

Colloidal Superstructures in Space

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University of Amsterdam
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Science Team



Dr. Sandra Veen
(Amsterdam)



Dr. Marco Potenza
(Milan)



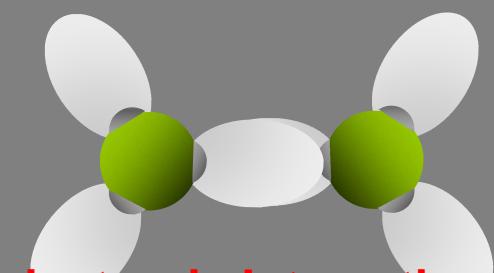
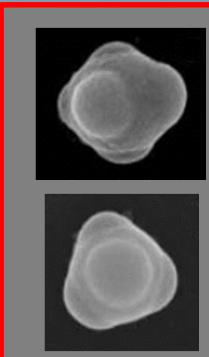
Prof. Gerard Wegdam
(Amsterdam)



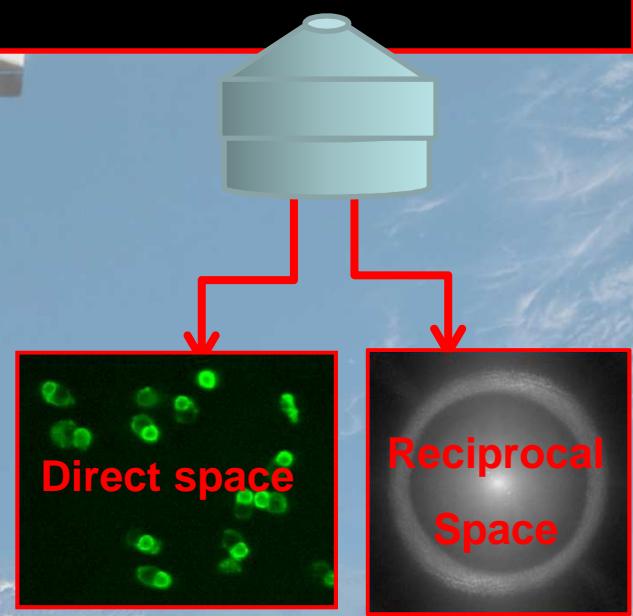
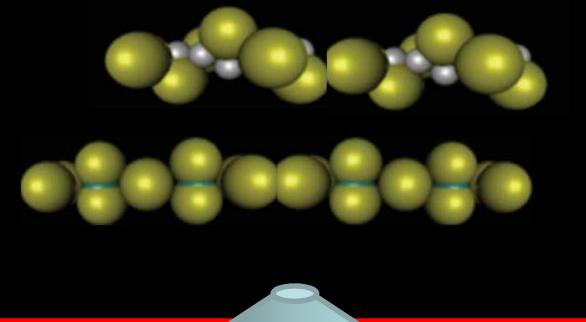
Dr. Peter Schall
(Amsterdam)

Colloidal Superstructures in Space

- Anisotropic interactions
- T control of interactions
- Superstructures:
Formation + Growth
- Direct + reciprocal imaging

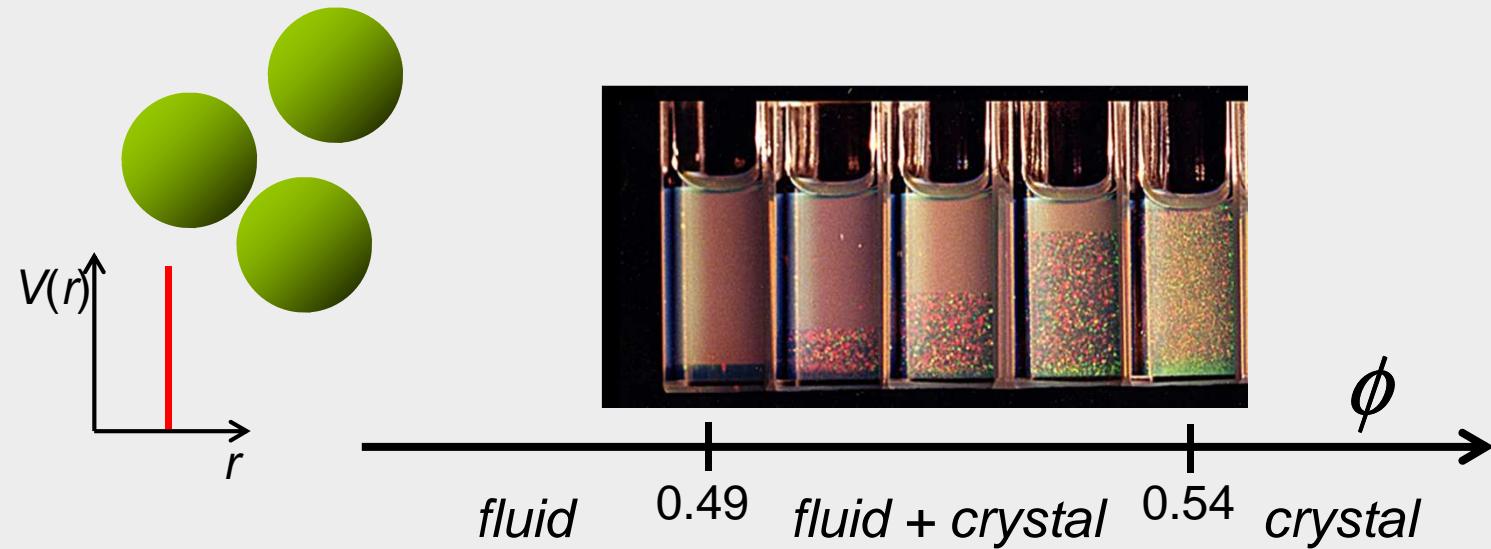


Anisotropic Interaction
by critical Casimir forces



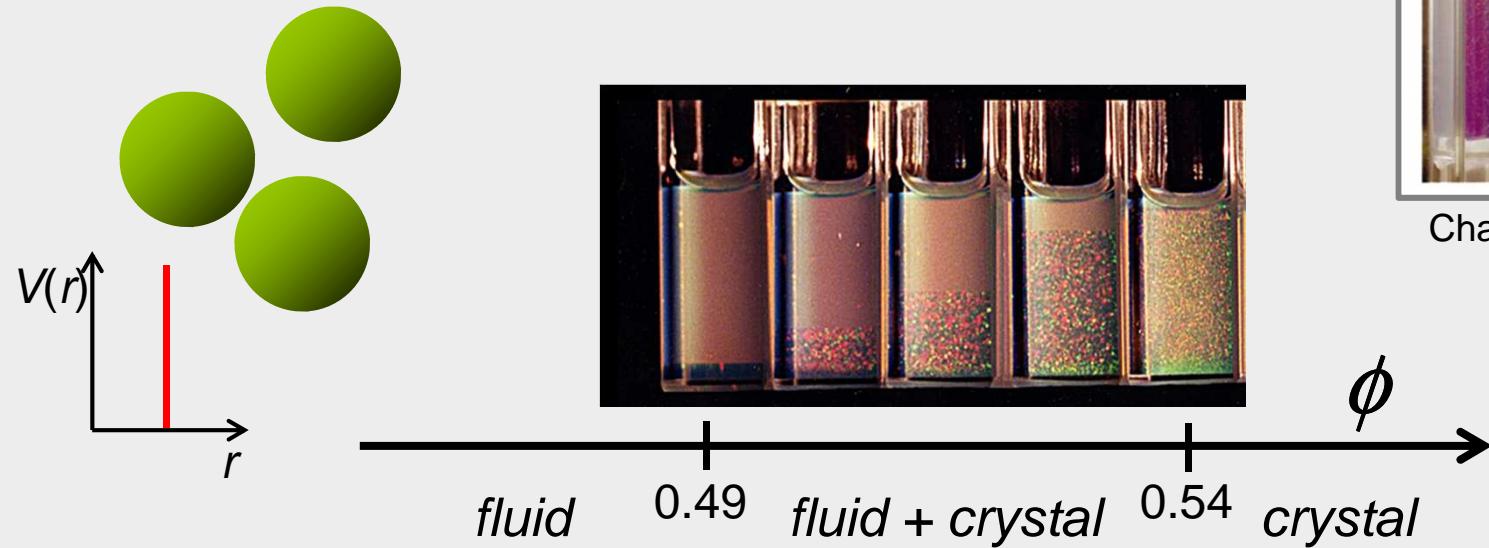
Science Overview

Colloids - Hard Spheres



Science Overview

Colloids - Hard Spheres

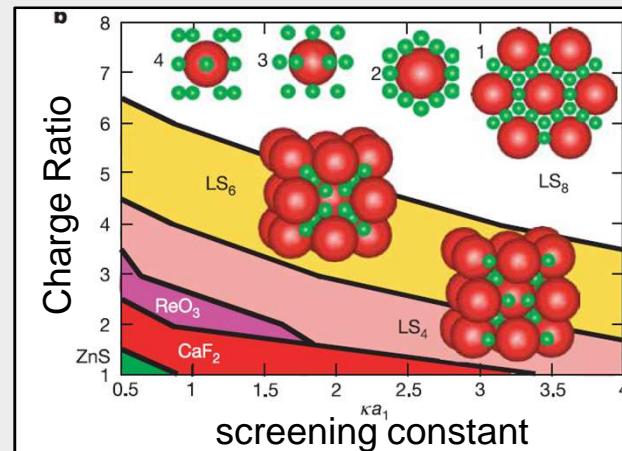
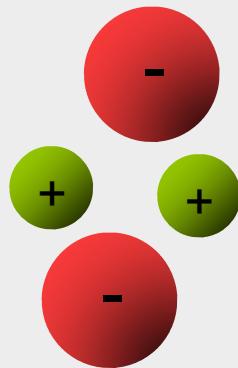


Chaikin, Russel et al.



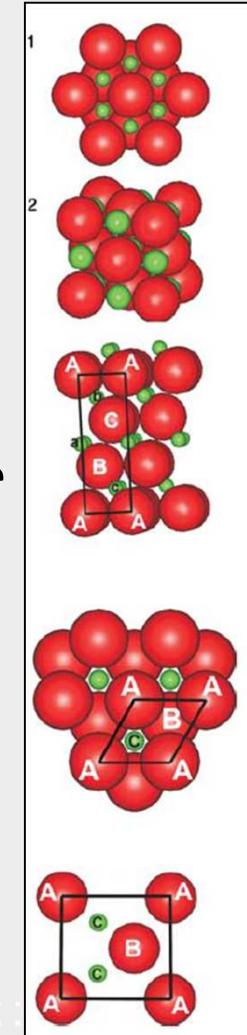
Science Overview

Colloids - Charged Spheres



Leunissen *et al.* (*Nature* 2005)

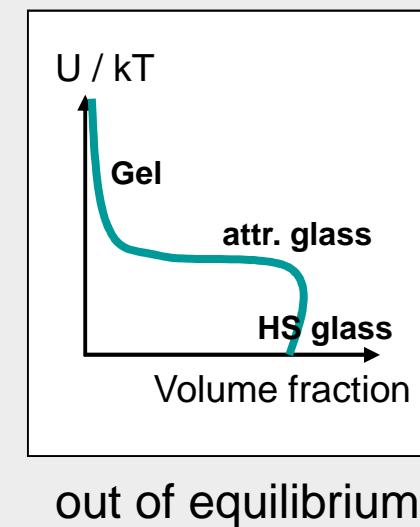
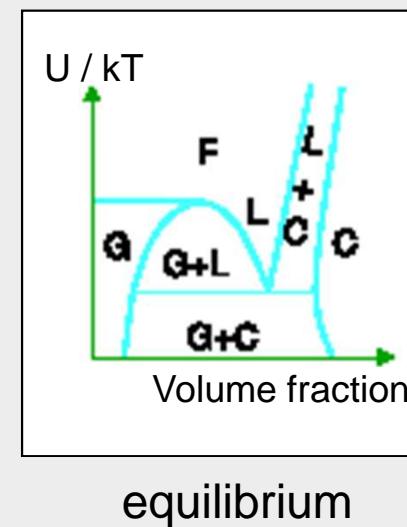
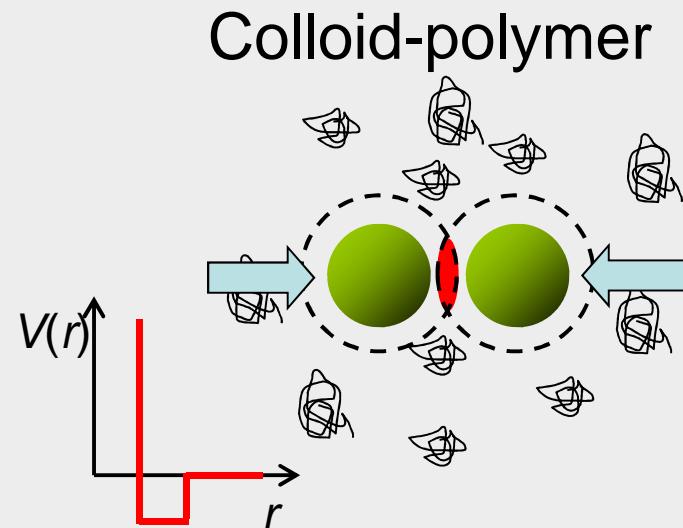
Ionic crystals





Science Overview

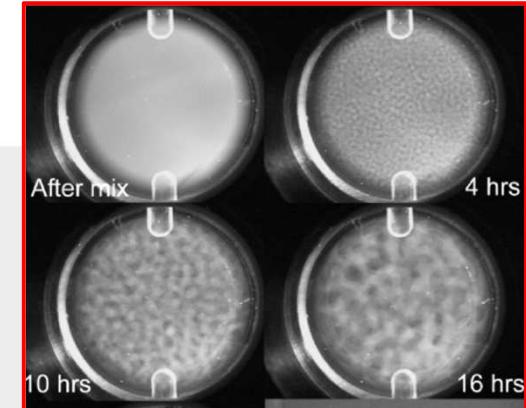
Colloidal Phase behavior - Depletion





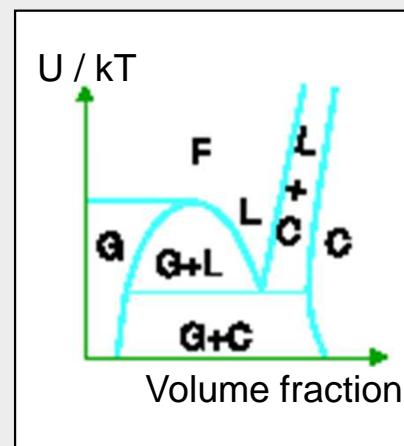
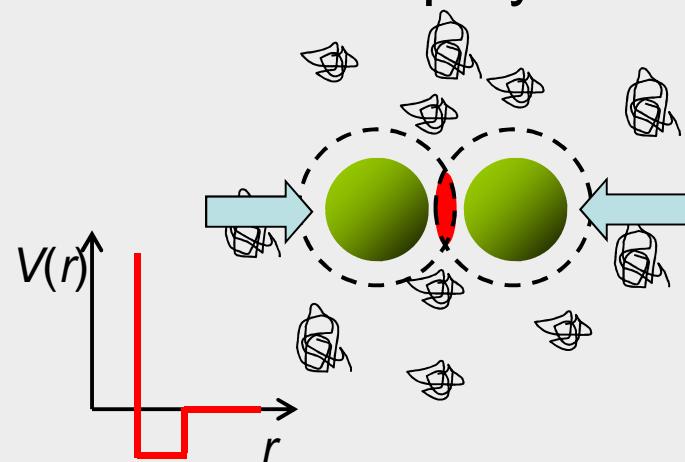
Science Overview

Colloidal Phase behavior - Depletion

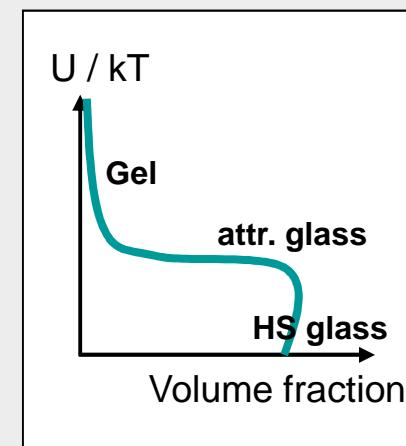


Chaikin, Weitz

Colloid-polymer



equilibrium

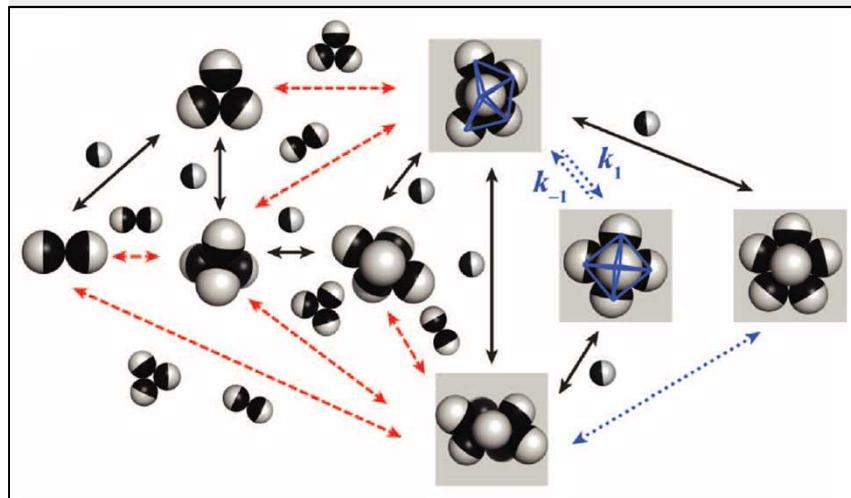
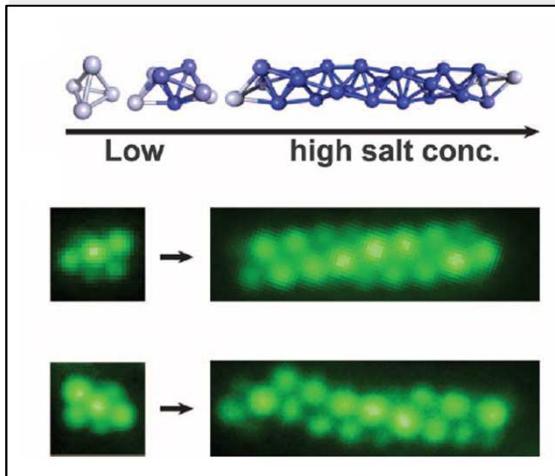


out of equilibrium



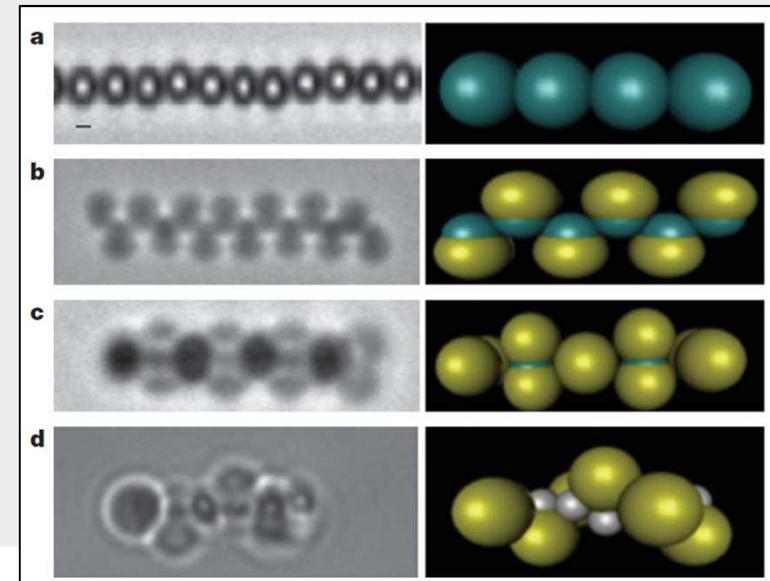
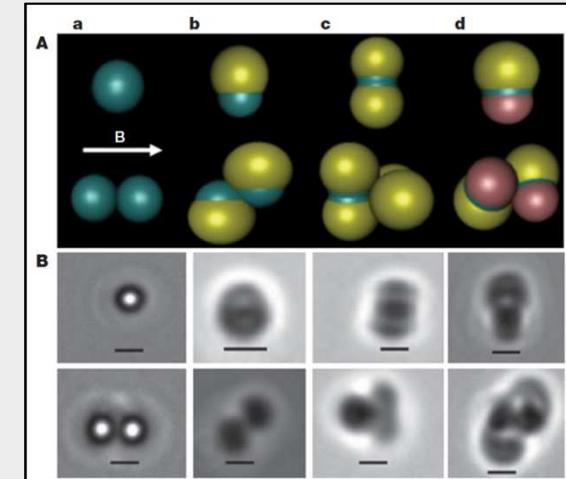
Science Overview

Anisotropic Interactions



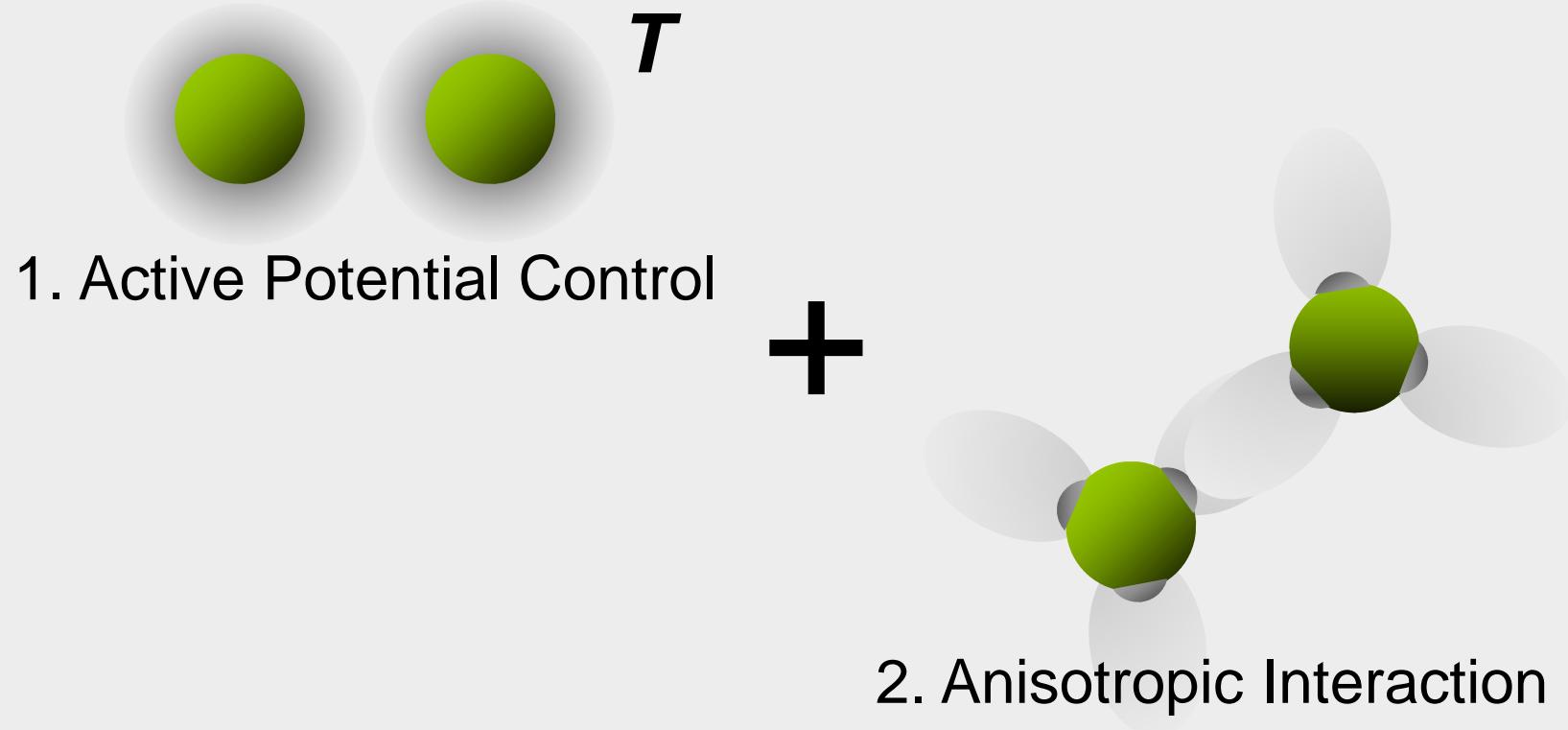
Q. Chen, J.K. Whitmer, S. Jiang, S.C. Bae,
E. Luijten, S. Granick ,*Science*, 331 (2011)
199-202

D. Zerrouki, J Baudry, D. Pine, P. Chaikin,
J. Bibette, *Science*, 455 (2008) , 380-382



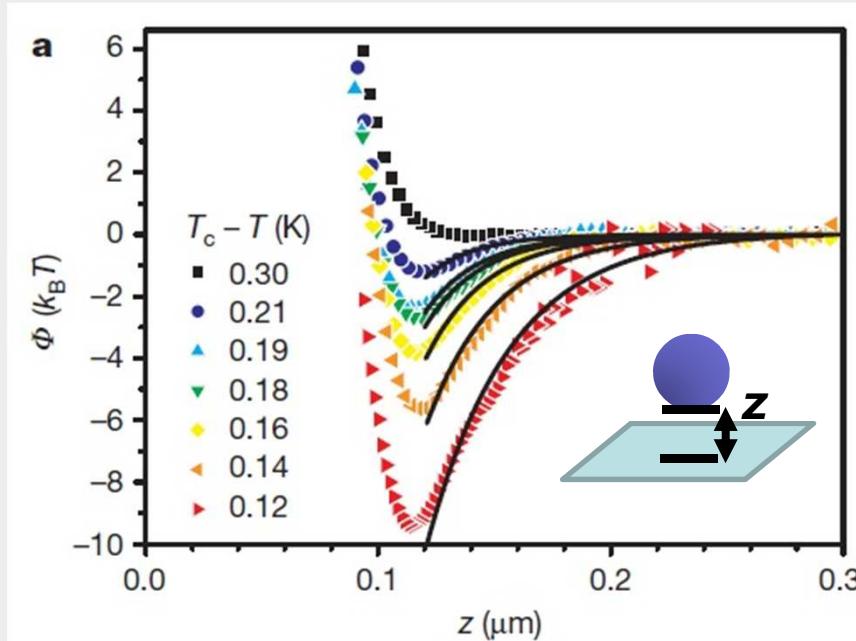
Science Overview

Control Interactions - Critical Casimir effect



Science Overview

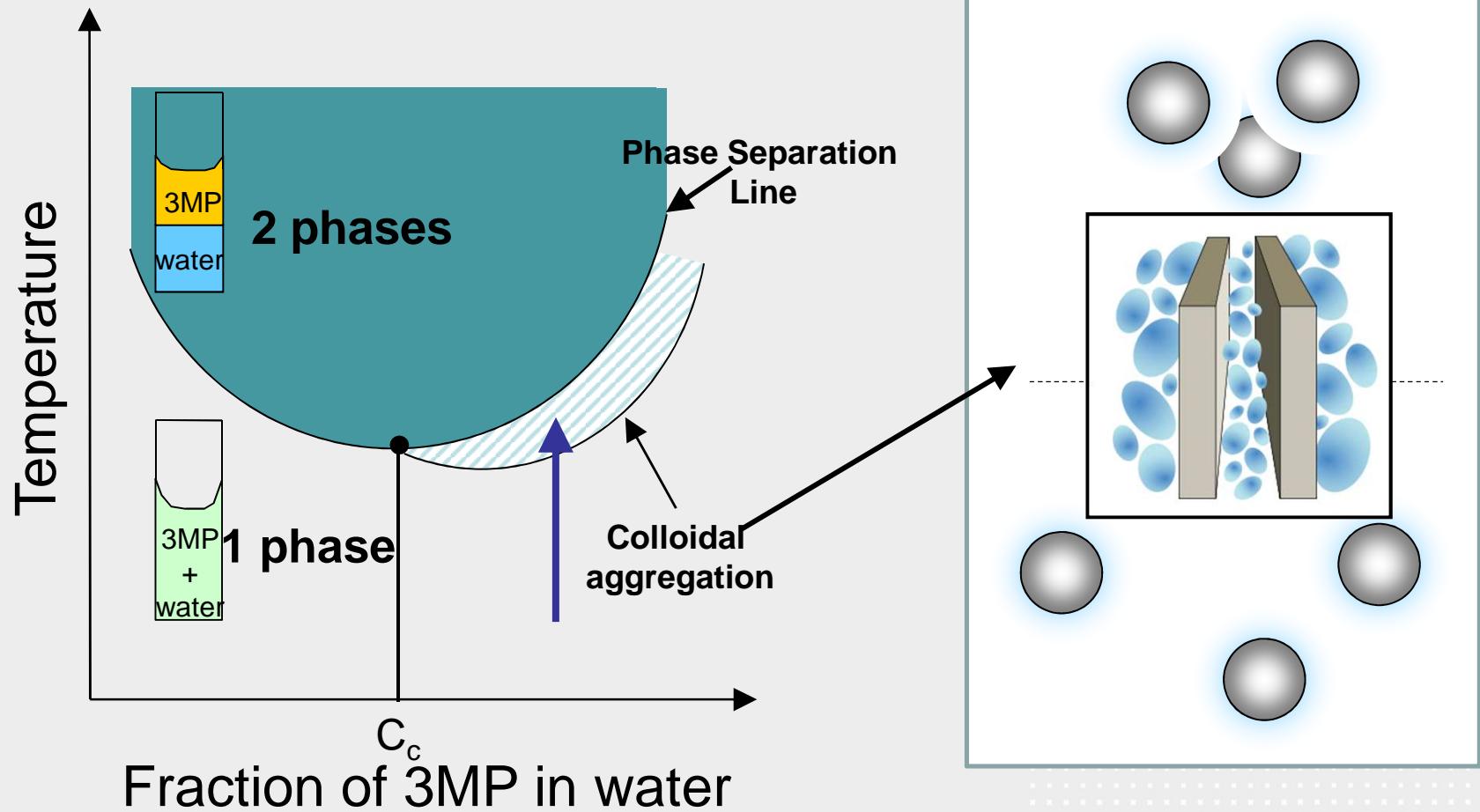
Control Interactions - Critical Casimir effect



Bechinger et al. (*Nature* 2008)

Science Overview

The Critical Casimir effect



Science Overview

Particle interactions

Coulomb repulsion

$$V_{el}(a) \propto \lambda_d^2 e^{-a/\lambda_d}$$

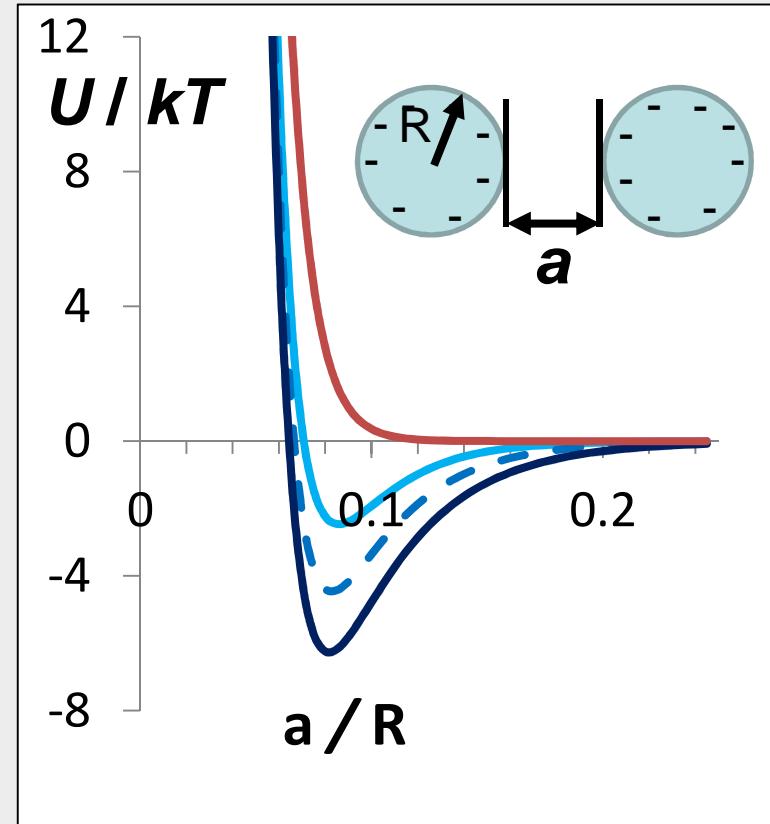
$\lambda_d \rightarrow$ Salt concentration

+

Casimir attraction

$$V_{casimir}(a) \propto -\frac{1}{\xi} e^{-a/\xi}$$

$\xi \rightarrow$ Temperature



Science Overview

Particle interactions

Coulomb repulsion

$$V_{el}(a) \propto \lambda_d^2 e^{-a/\lambda_d}$$

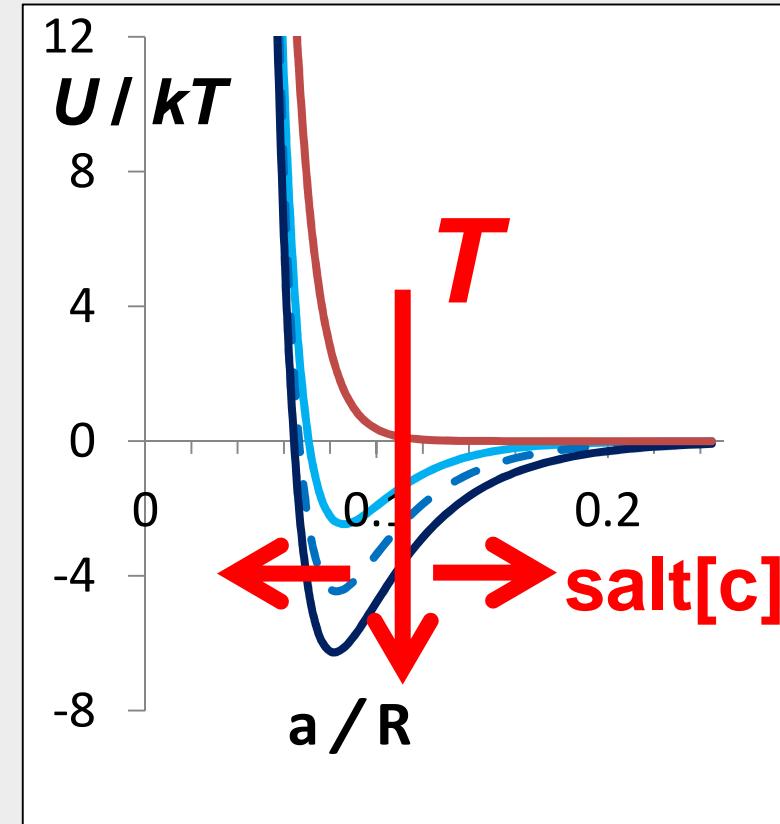
$\lambda_d \rightarrow$ Salt concentration

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Casimir attraction

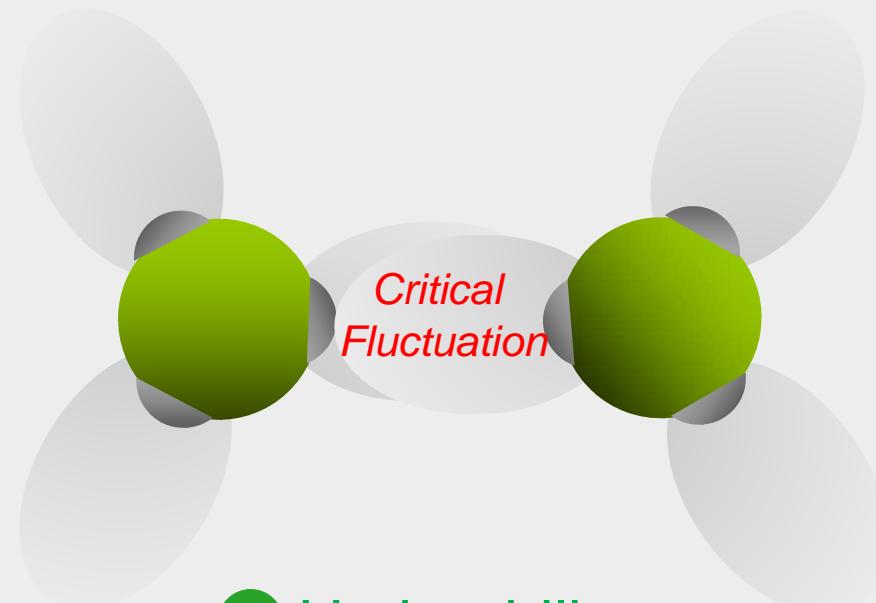
$$V_{casimir}(a) \propto -\frac{1}{\xi} e^{-a/\xi}$$

$\xi \rightarrow$ Temperature



Scientific Merit

Control Anisotropic Interactions



● Hydrophilic
● Hydrophobic



Scientific Merit

Control Anisotropic Interactions

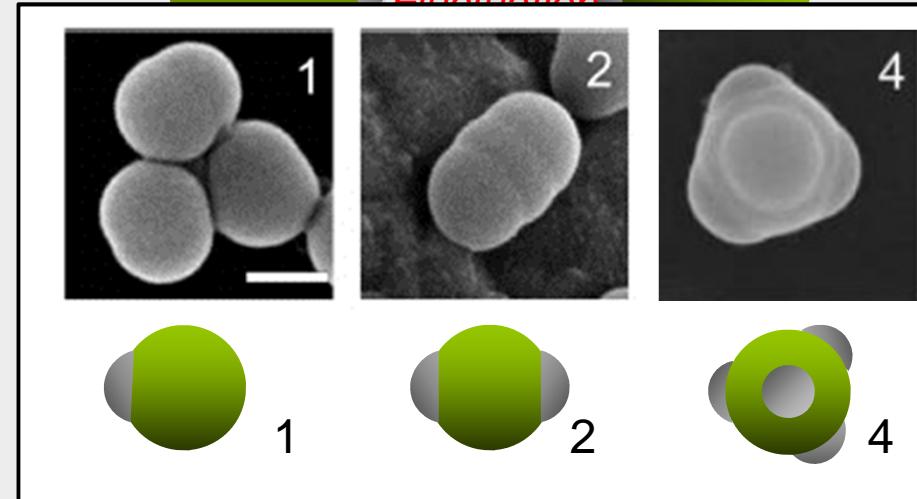
Living polymer chains
(Particles 2)

Diamond structure
(Particles 4)

**Colloidal Micelles
Helices**
(Particles 1)

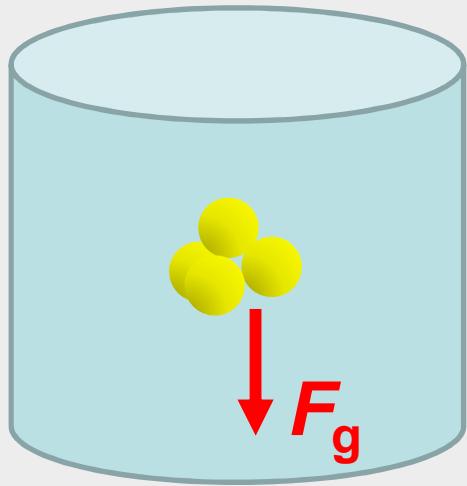
Molecules
(Particle Mixtures)

*Critical
Fluctuation*



Need for ISS environment

1. Follow the growth of structures

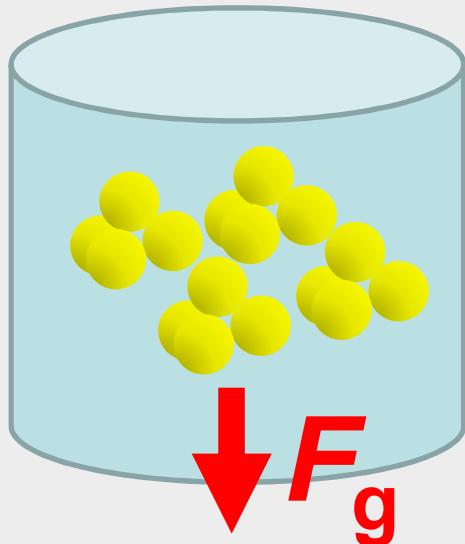


$$F_g = \Delta\rho g V$$

$$\Delta\rho = \rho_{\text{Colloid}} - \rho_{\text{Solvent}}$$

Need for ISS environment

1. Follow the growth of structures

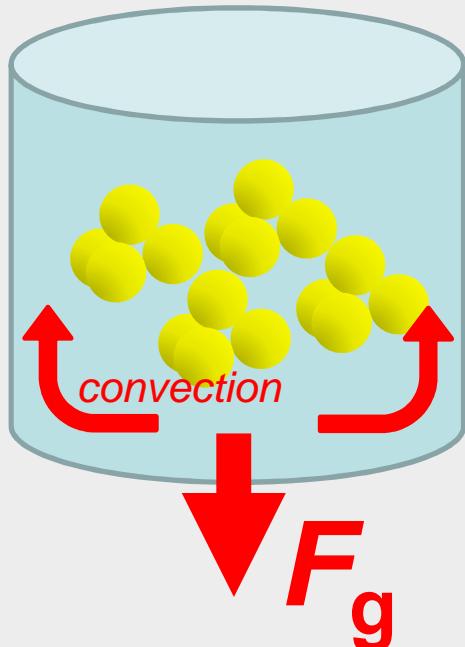


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Need for ISS environment

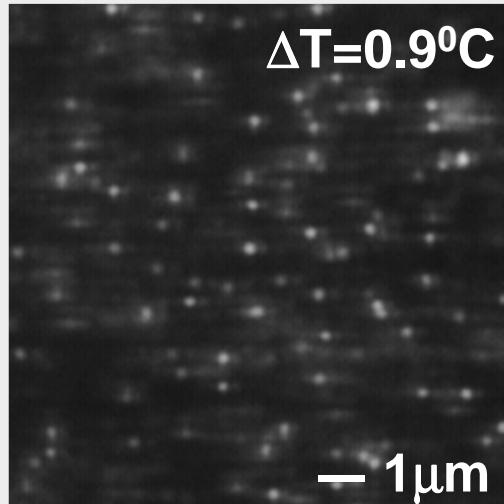
2. Temperature is control parameter



- Change Temperature
 $\Delta\rho$ changes
- Temperature → Convection
disrupts growth

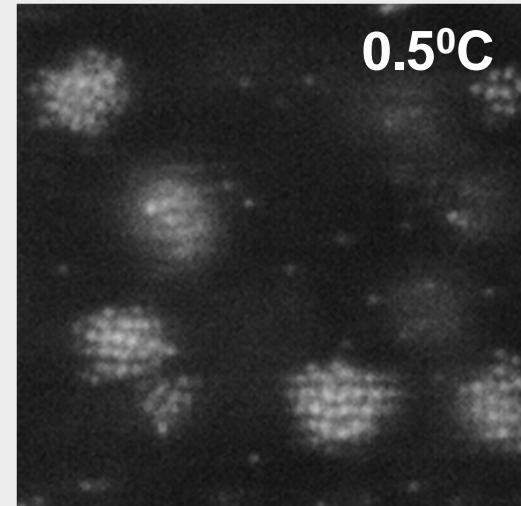
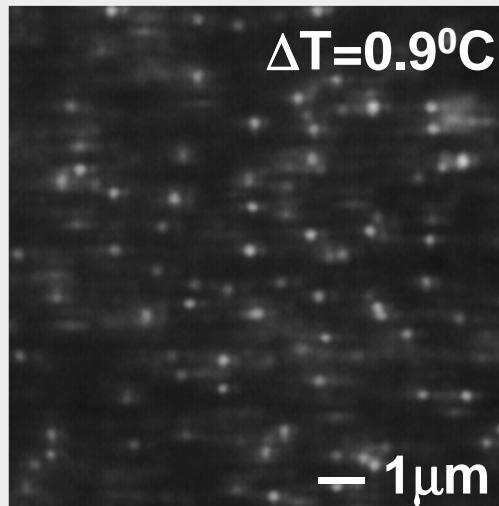
Ground-based work

Microscopy



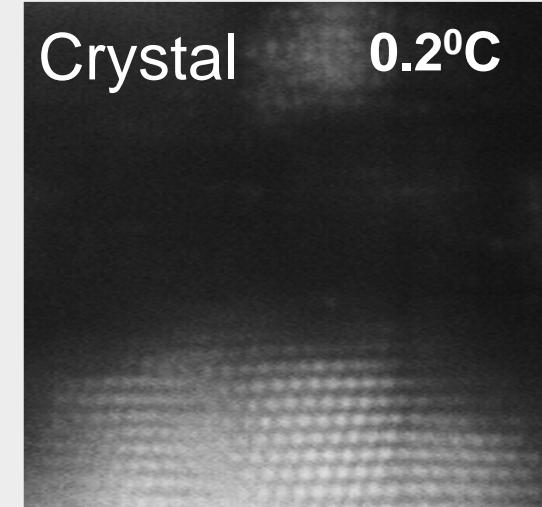
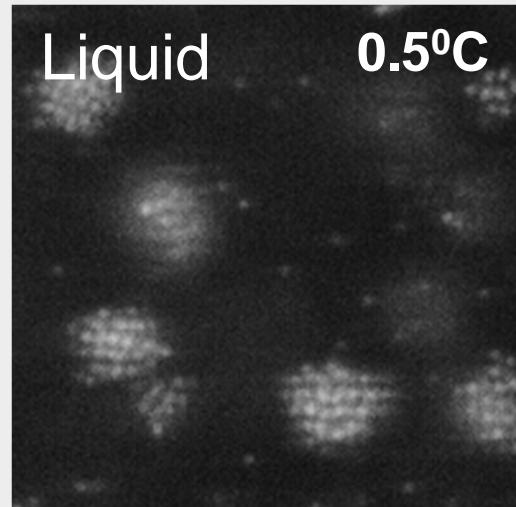
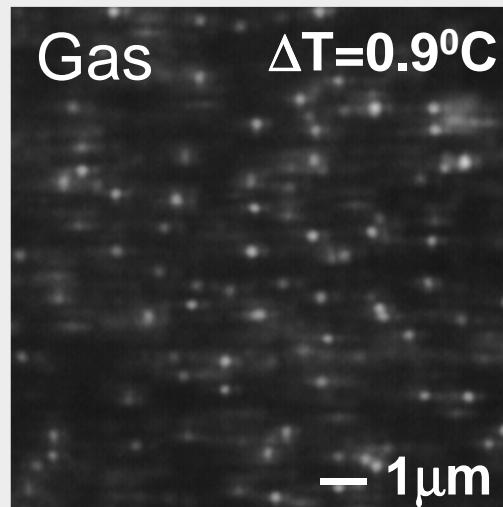
Ground-based work

Microscopy



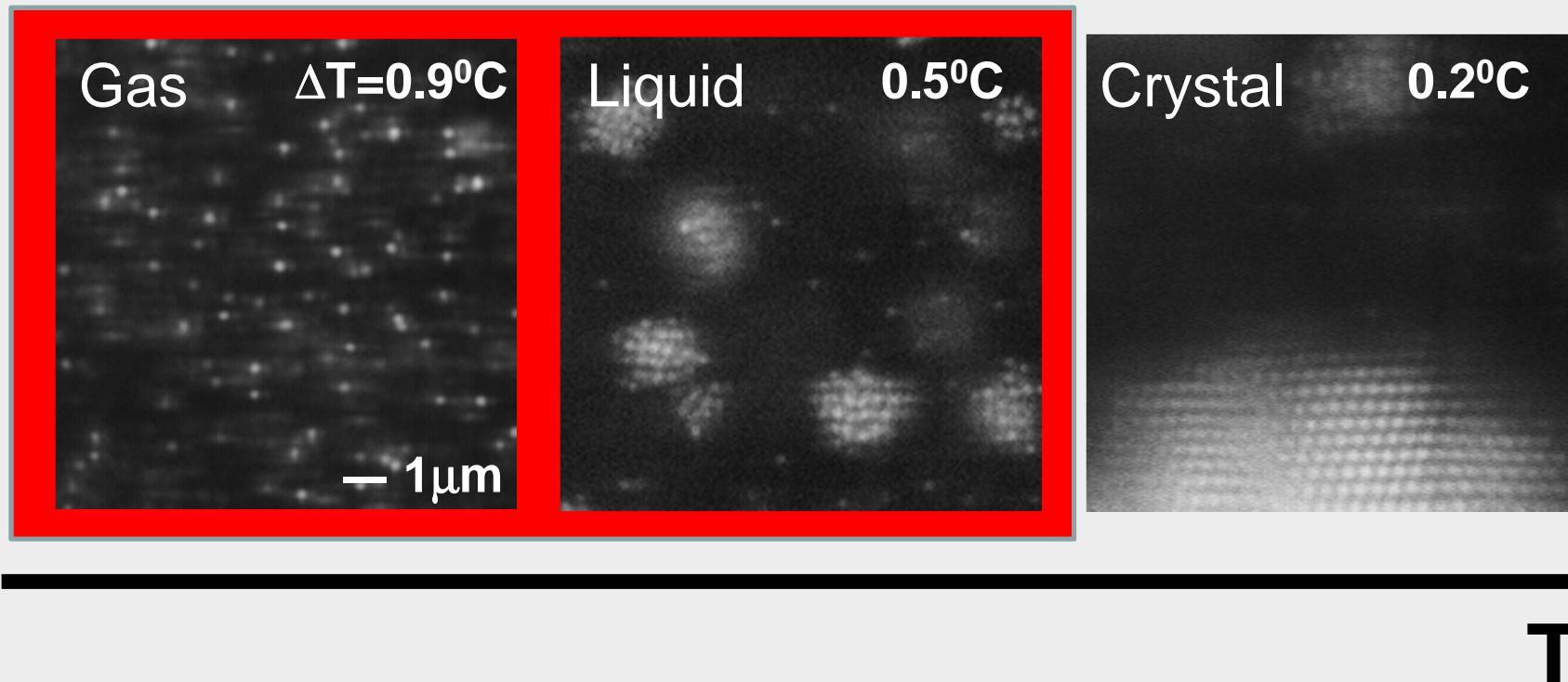
Ground-based work

Microscopy

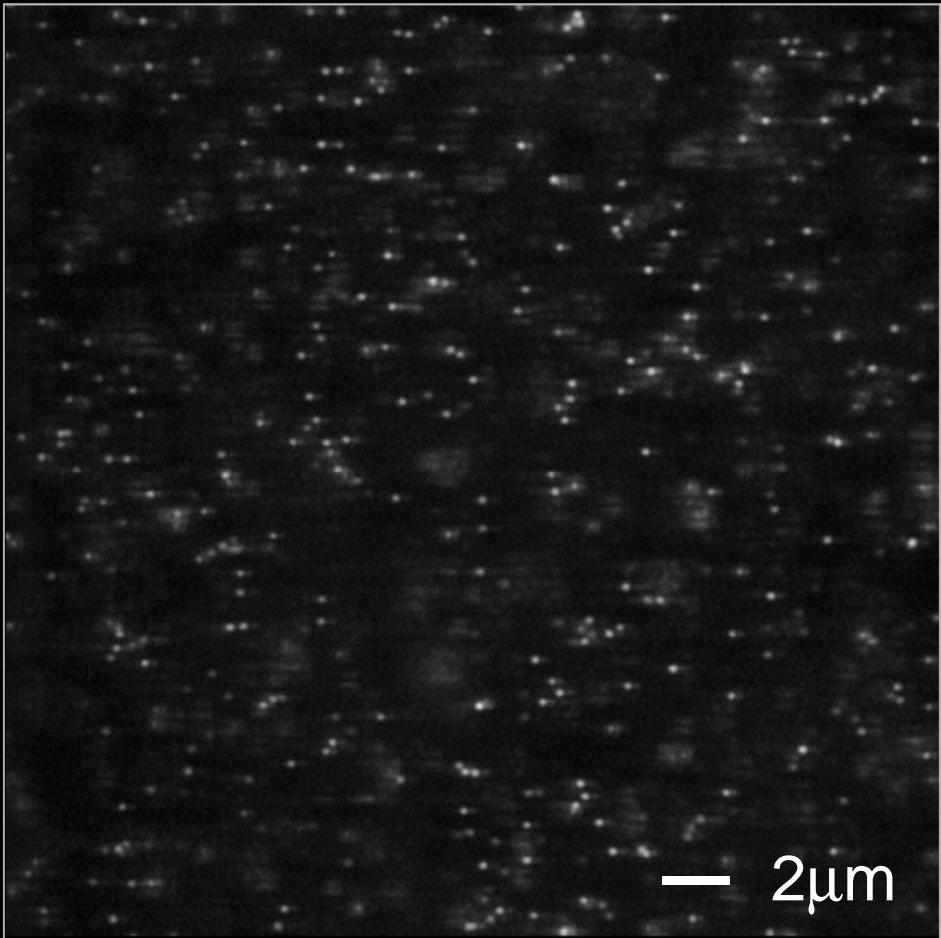


Ground-based work

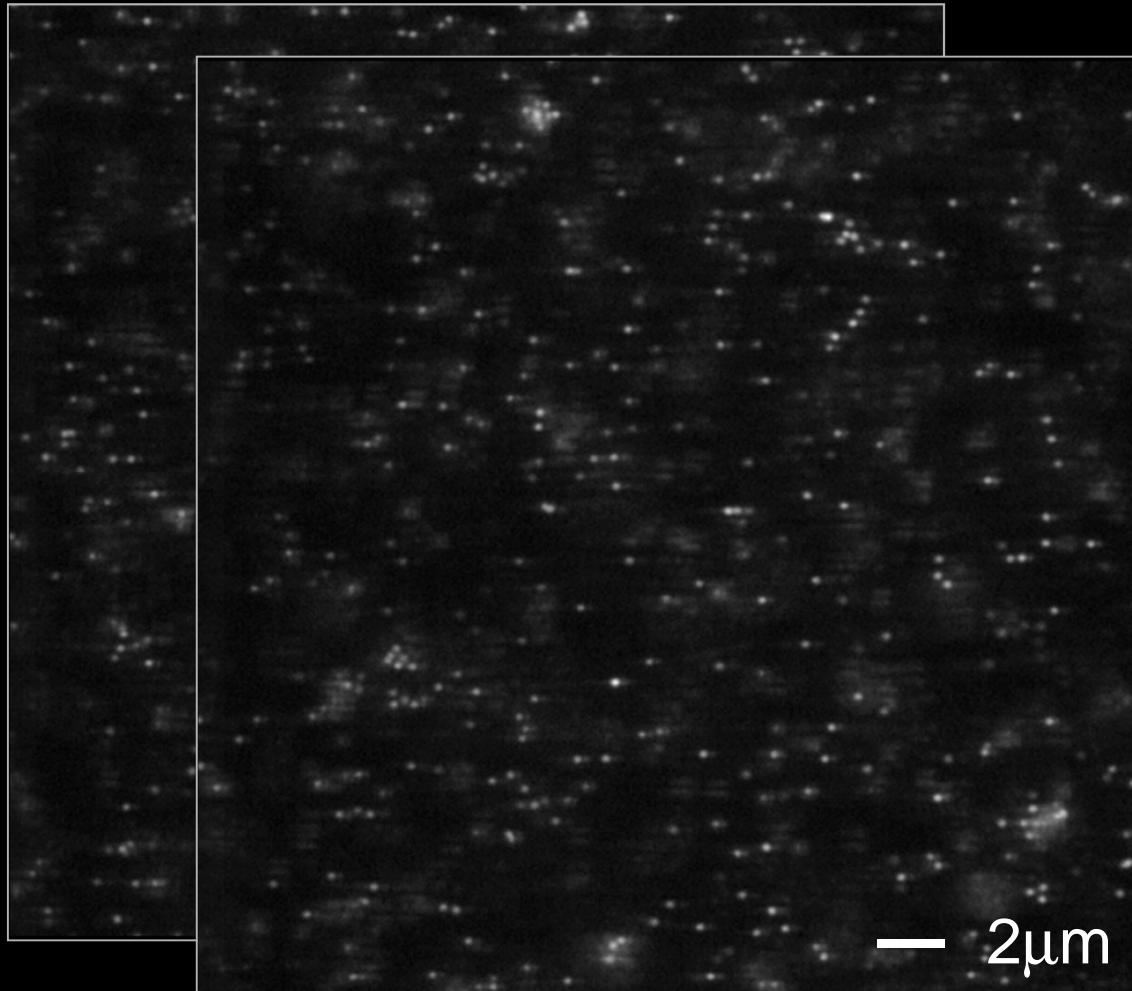
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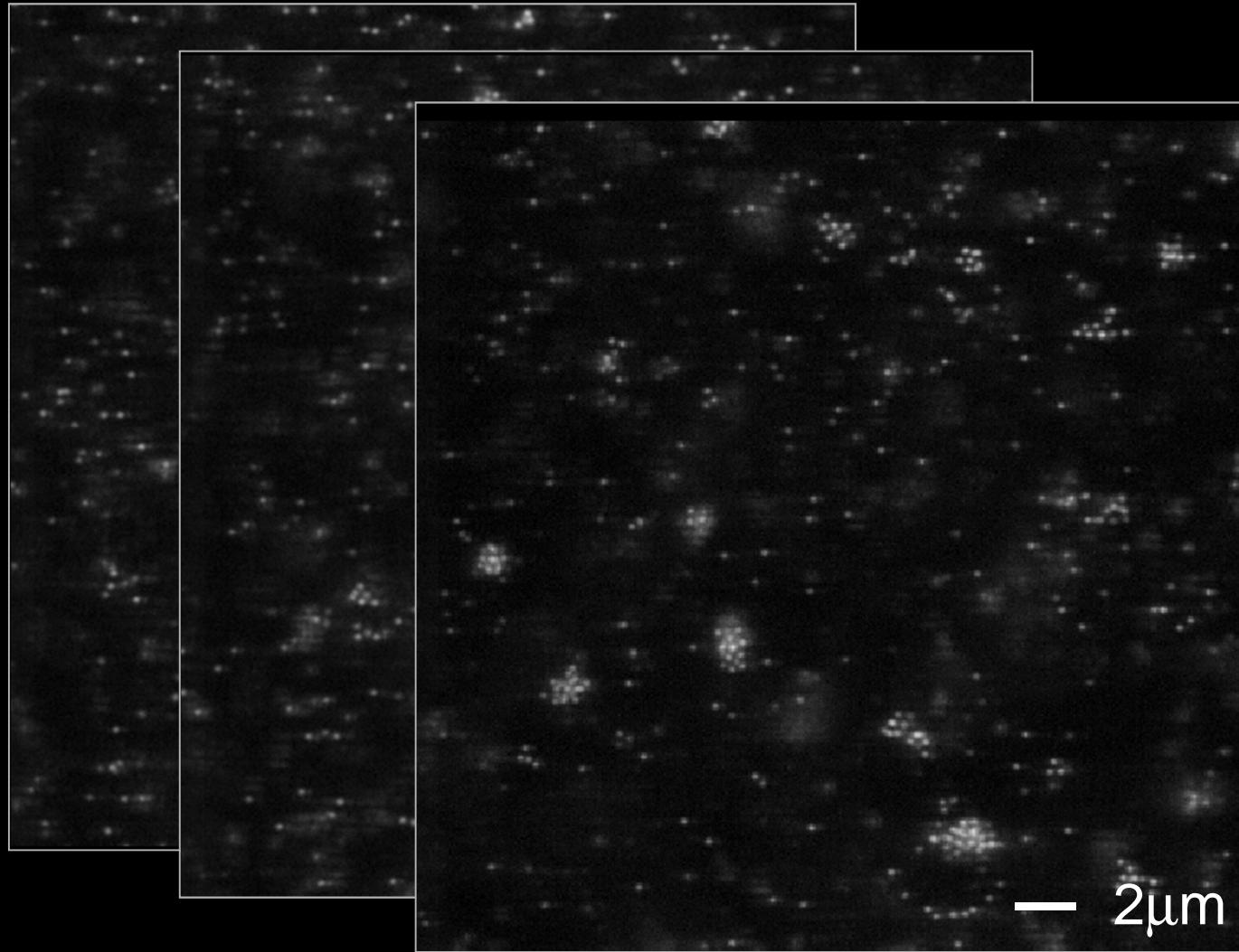
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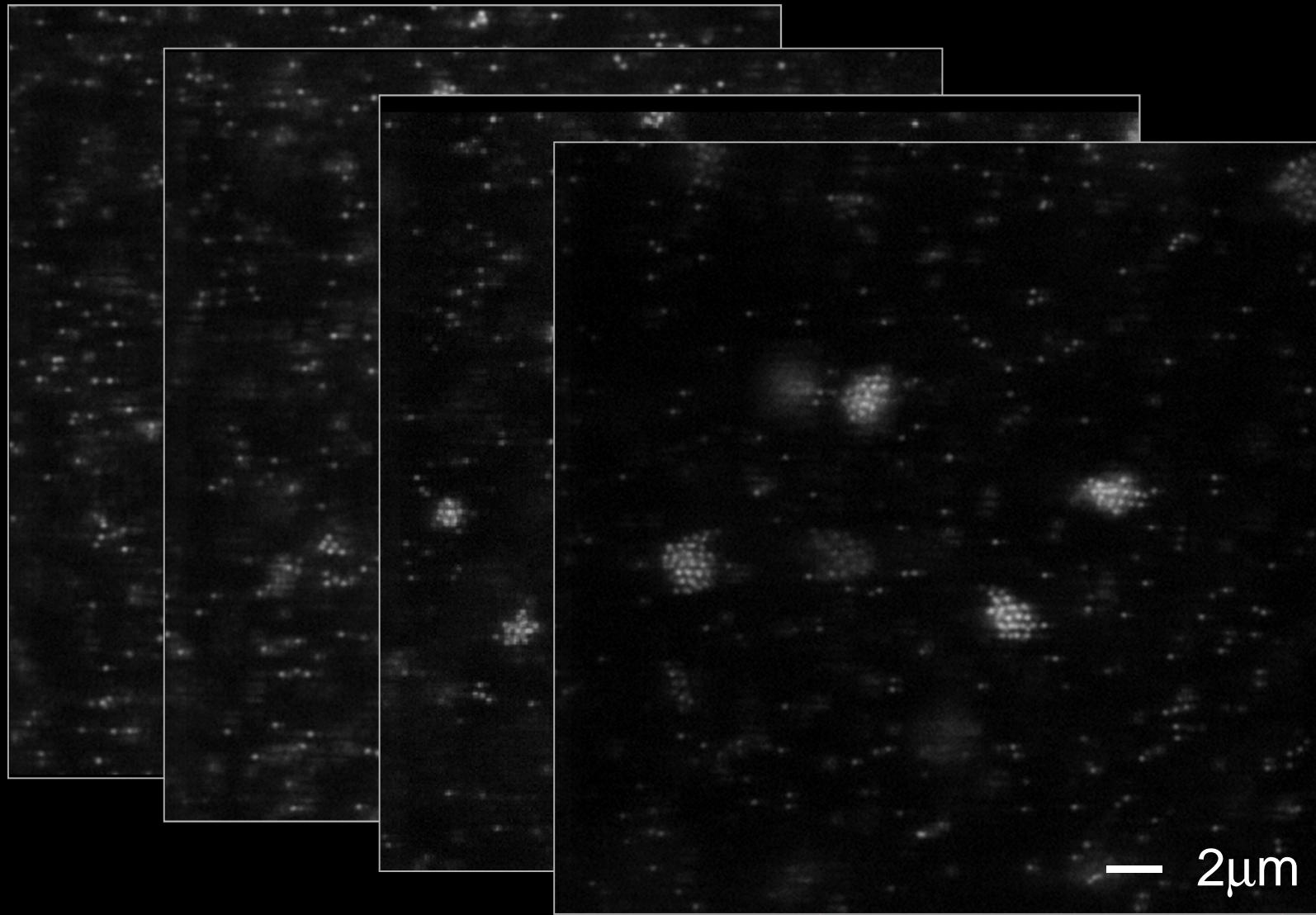
Microscopy



Microscopy



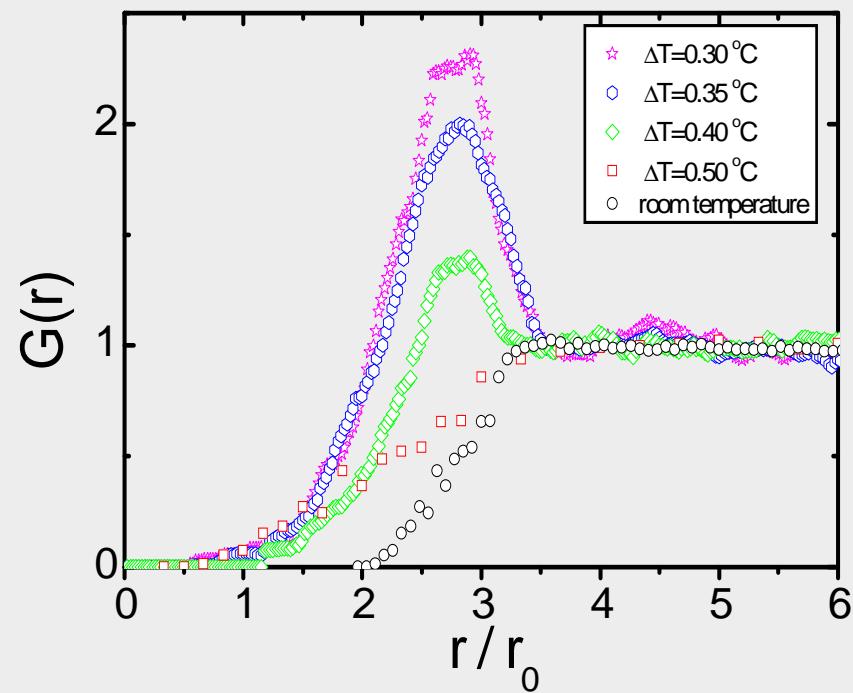
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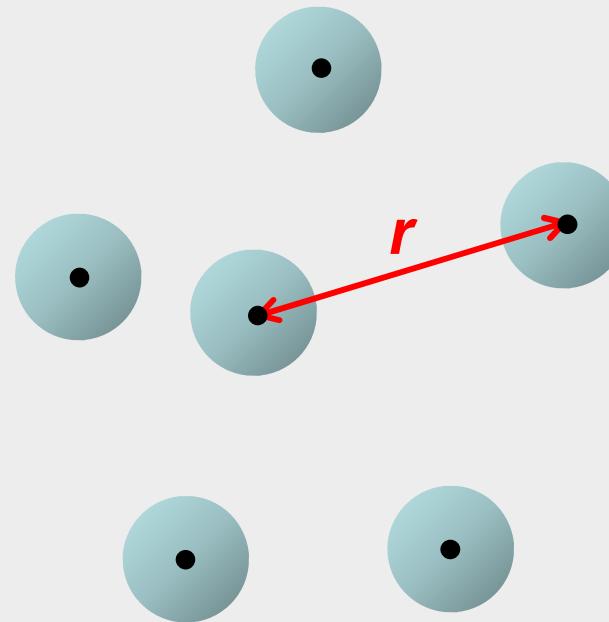
Ground-based work

Potential measurement

Pair distribution function



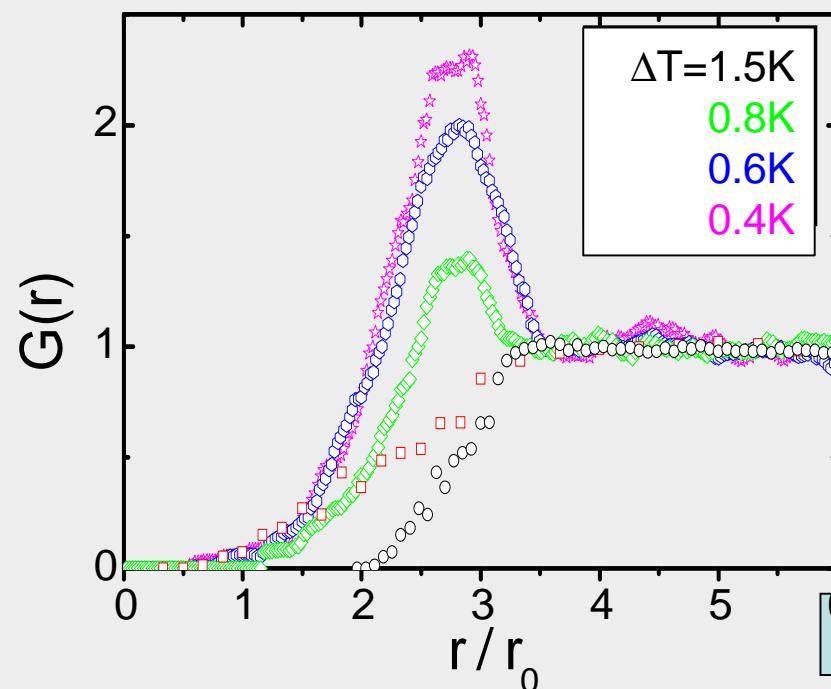
Particle distribution



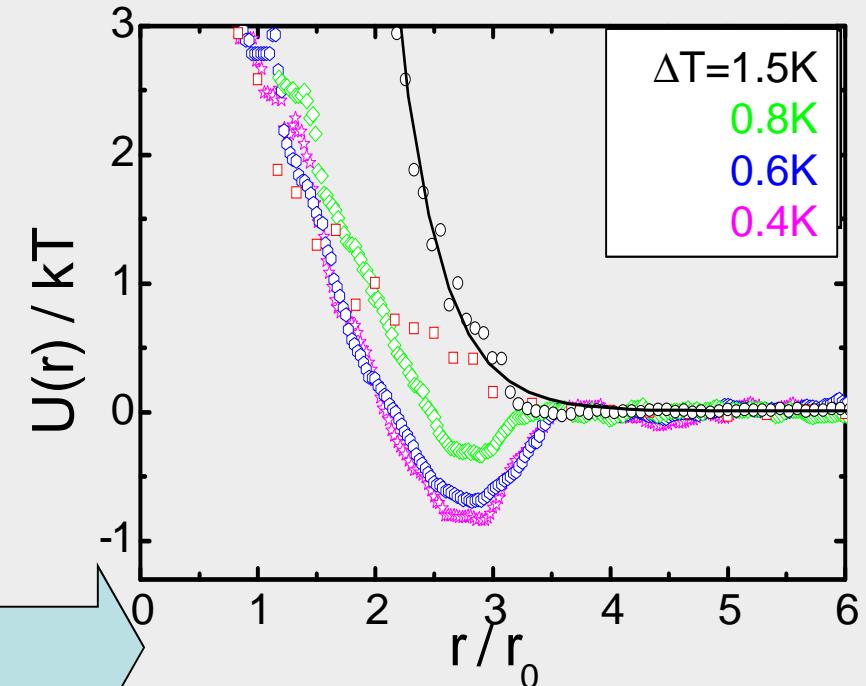
Ground-based work

Potential measurement

Pair distribution function



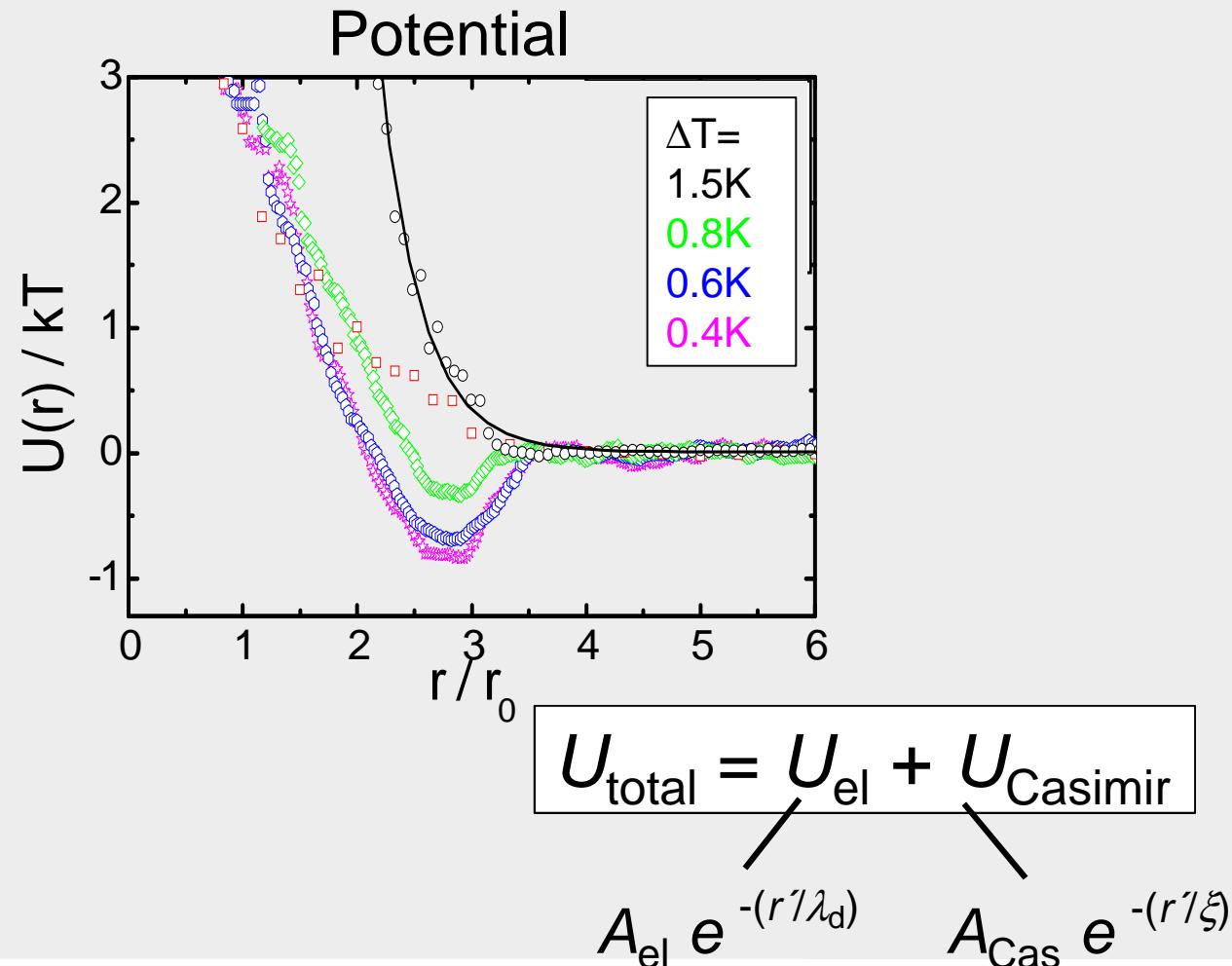
Potential



$$G(r) = \exp(-U(r) / k_B T)$$

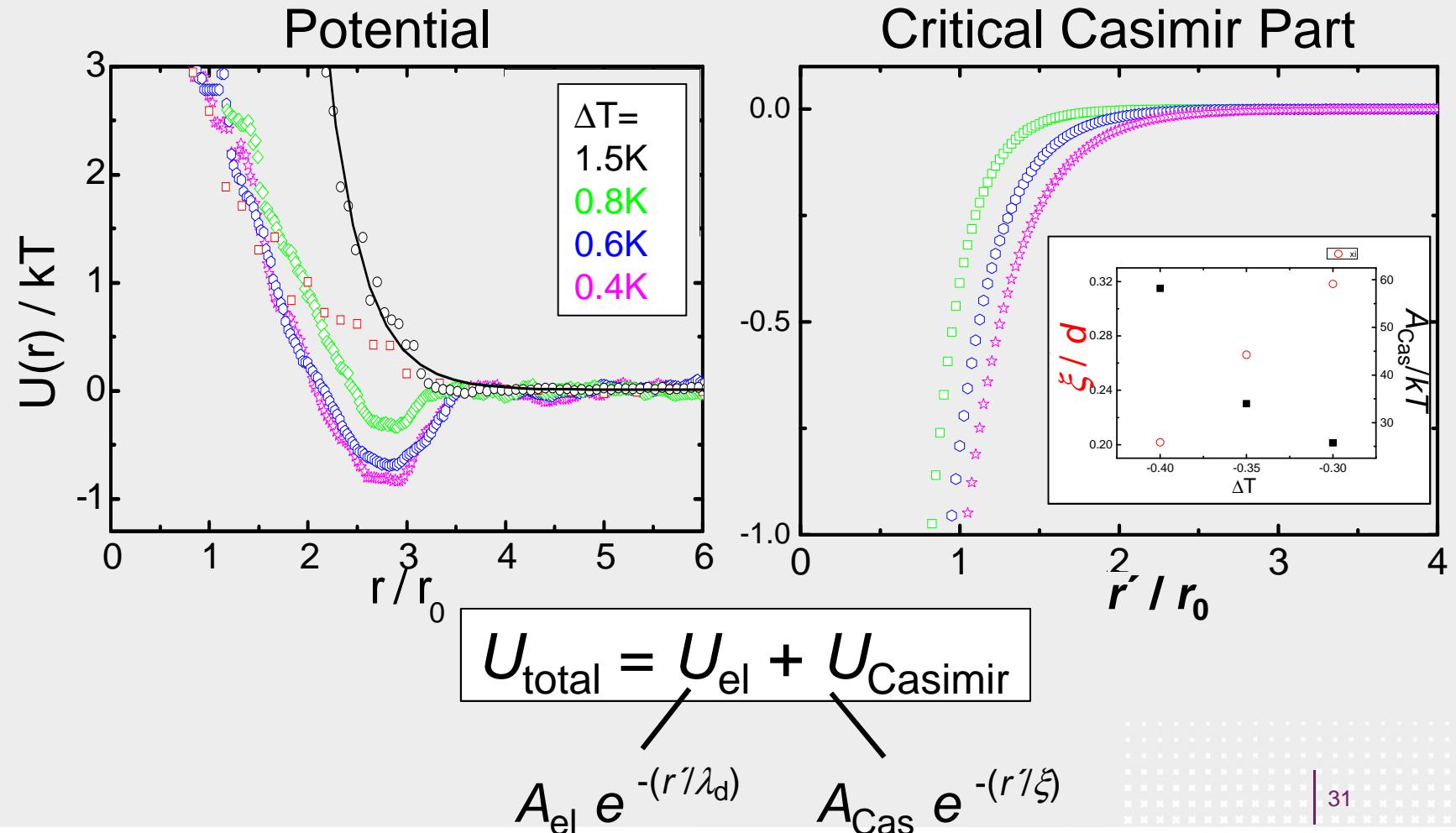
Ground-based work

Potential measurement



Ground-based work

Potential measurement





Ground-based work

Van der Waals model

$$(v - b) \left(p + \frac{a}{v^2} \right) = k_B T$$

Excluded volume

$$b = \frac{16}{3} \pi r_0^3$$

Effect. attraction

$$a = -2\pi \int_{r_1}^{\infty} U(r) r^2 dr$$

Israelachvilli, Intermolecular and surface forces

Ground-based work

Van der Waals model

$$(v - b) \left(p + \frac{a}{v^2} \right) = k_B T$$

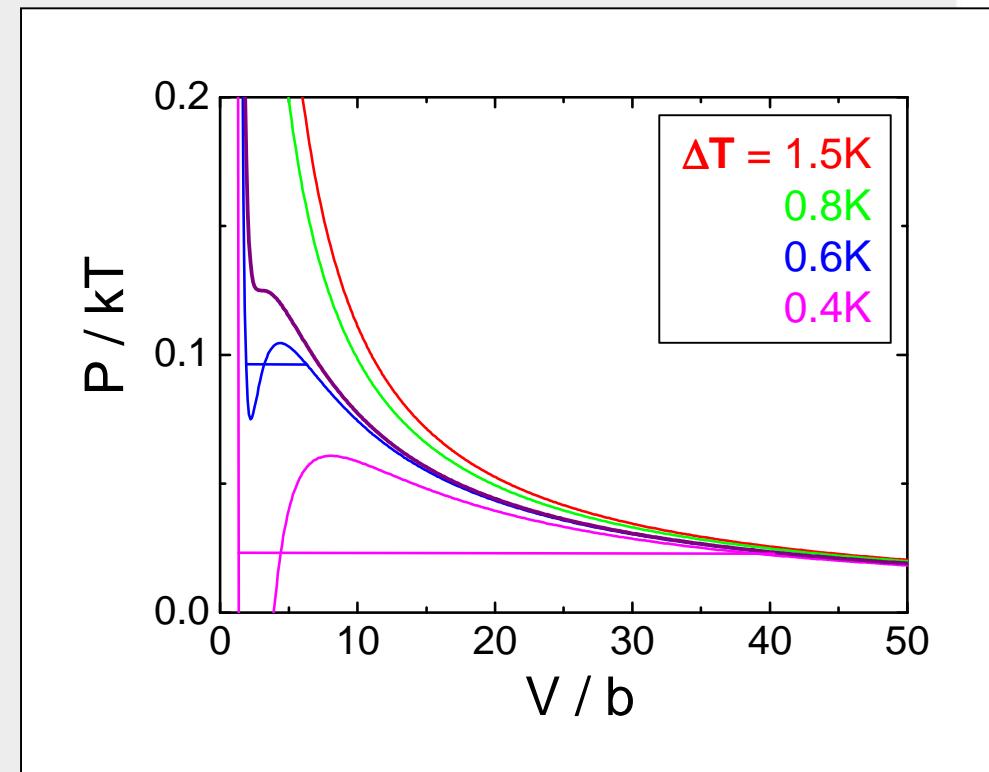
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Israelachvilli, Intermolecular and surface forces



Ground-based work

Van der Waals model

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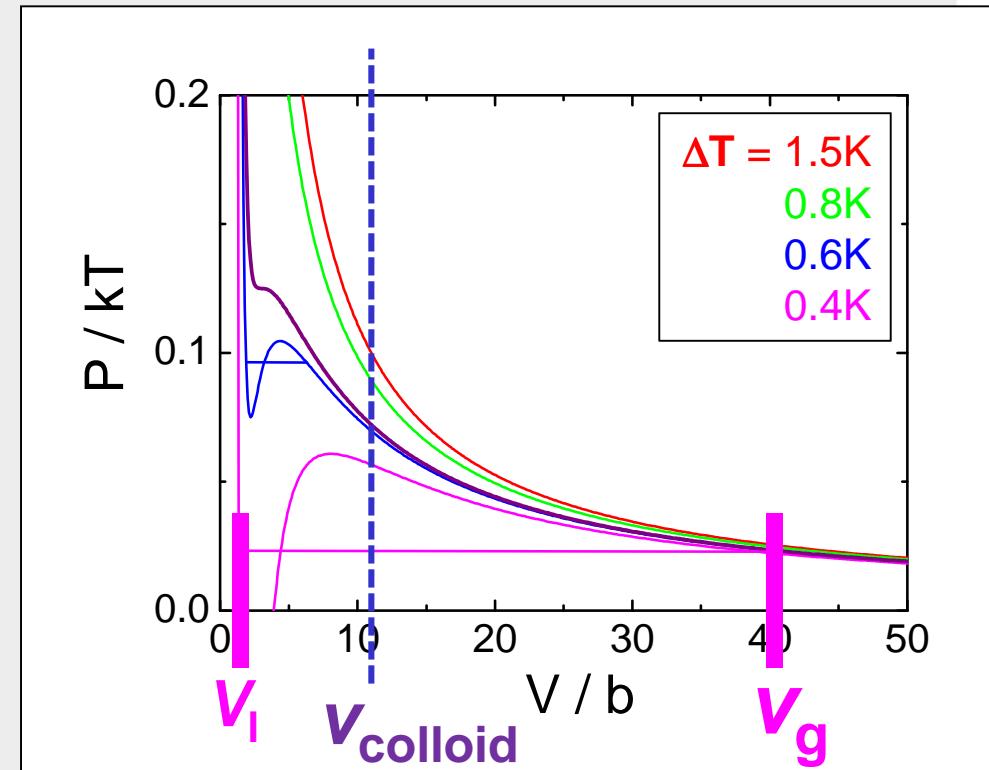
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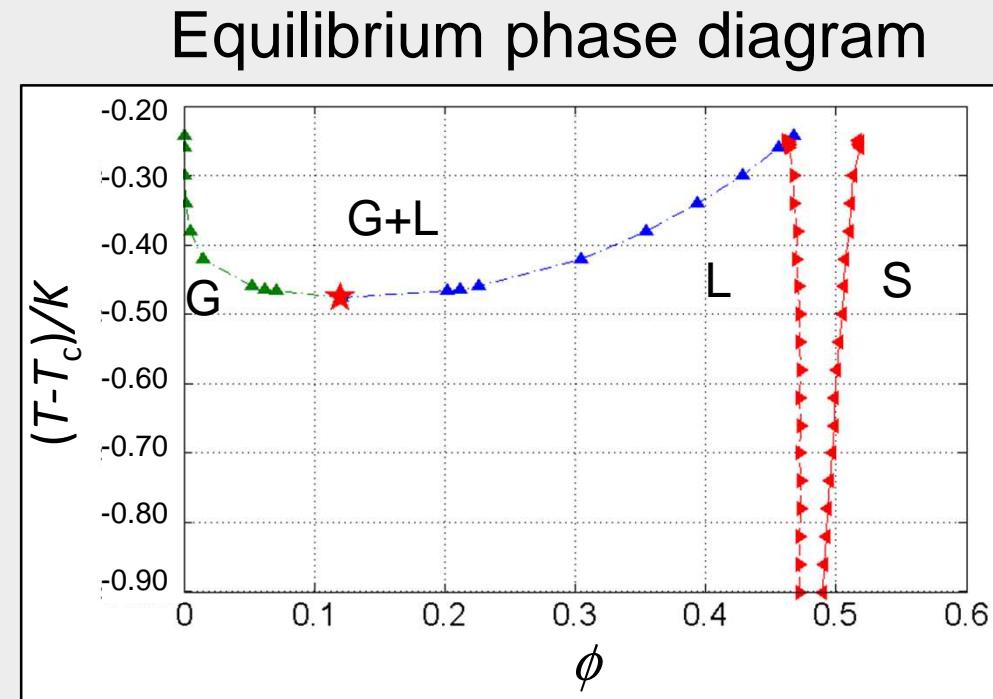
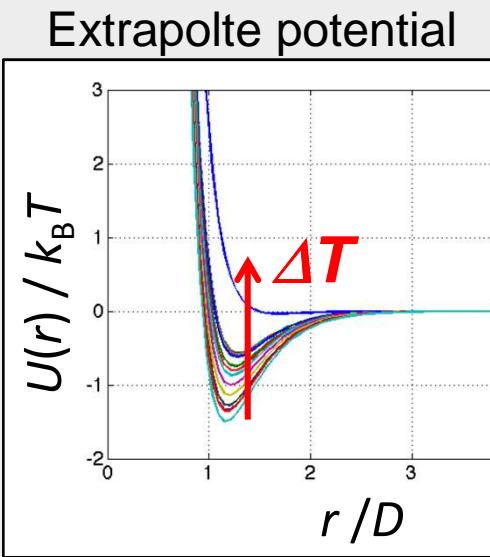
$$a = -2\pi \int_{r_1}^{\infty} U(r) r^2 dr$$

Israelachvili, Intermolecular and surface forces



Ground-based work

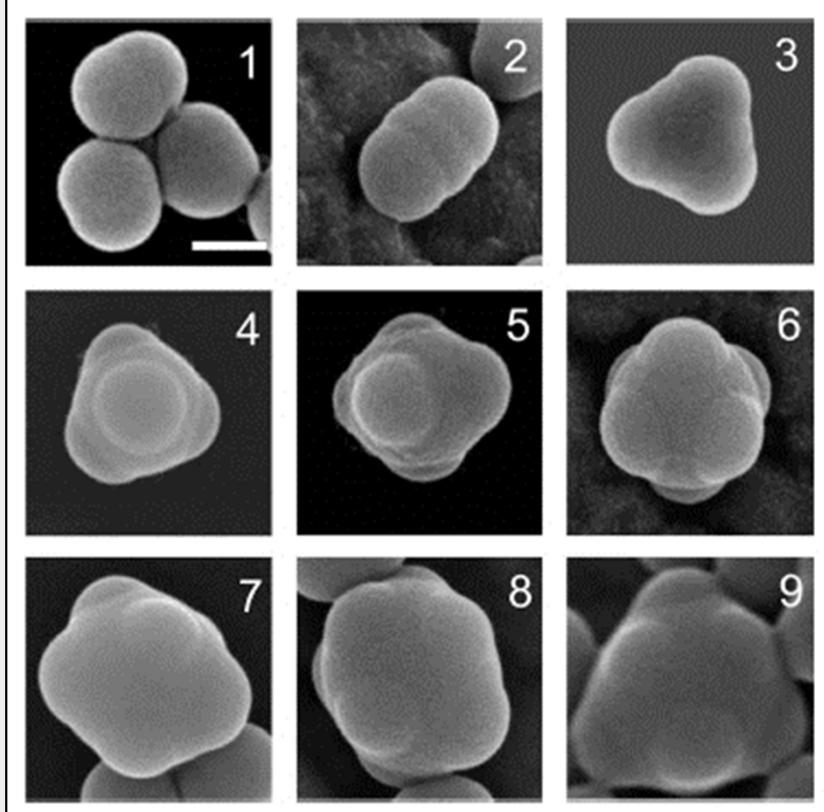
Monte Carlo Simulations



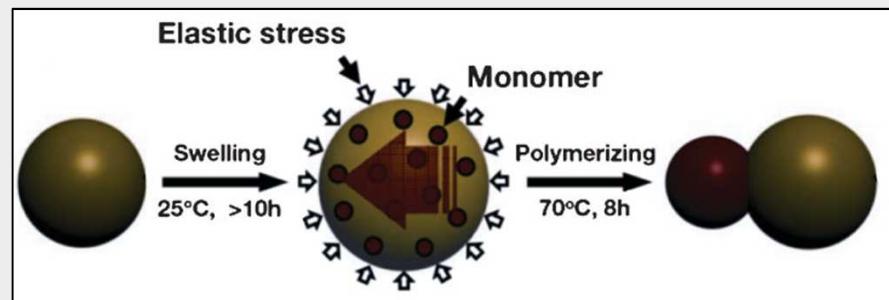


Ground-based work

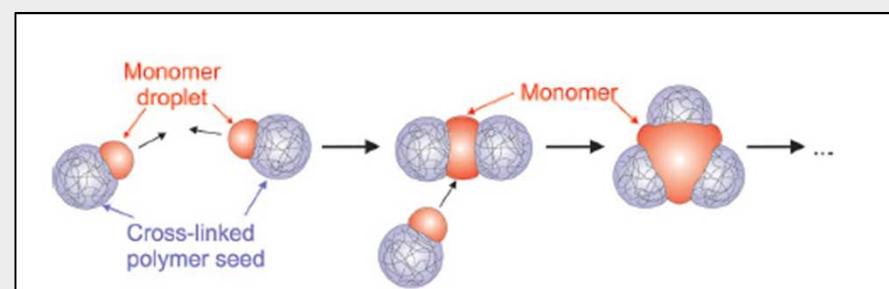
Colloidal Molecules



Single protrusion



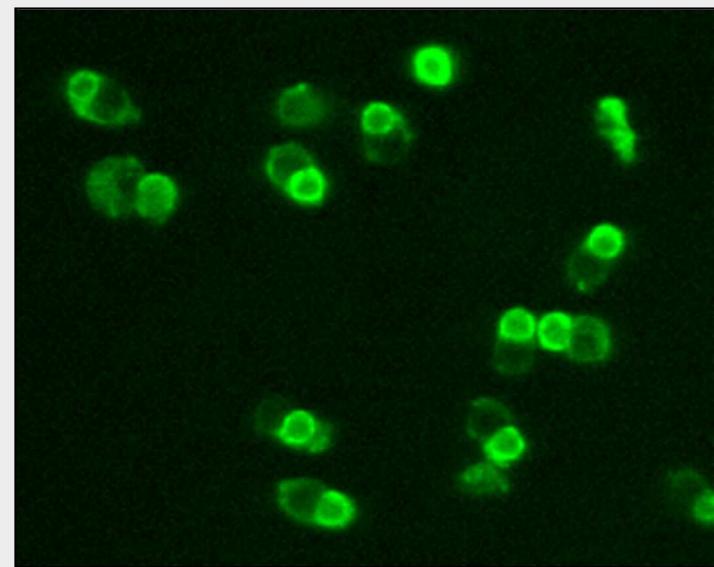
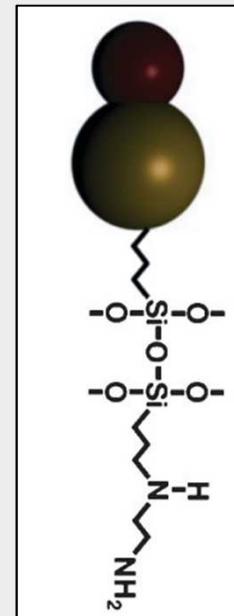
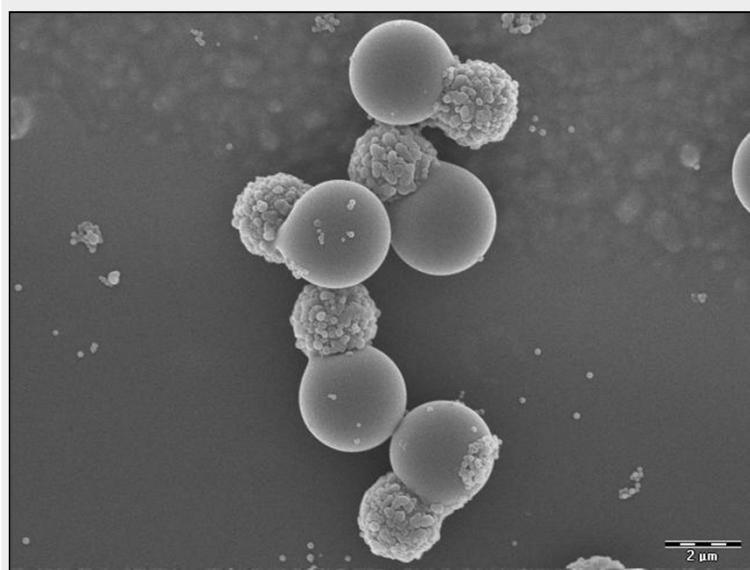
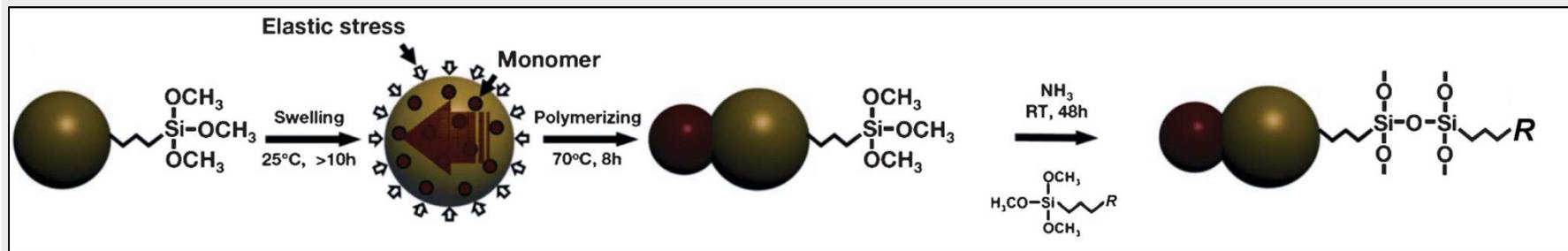
Making molecules





Ground-based work

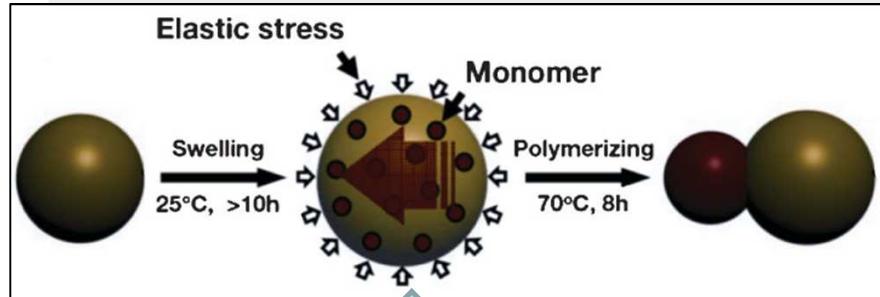
Adjusting the surface properties





Ground-based work

Adjusting the surface properties

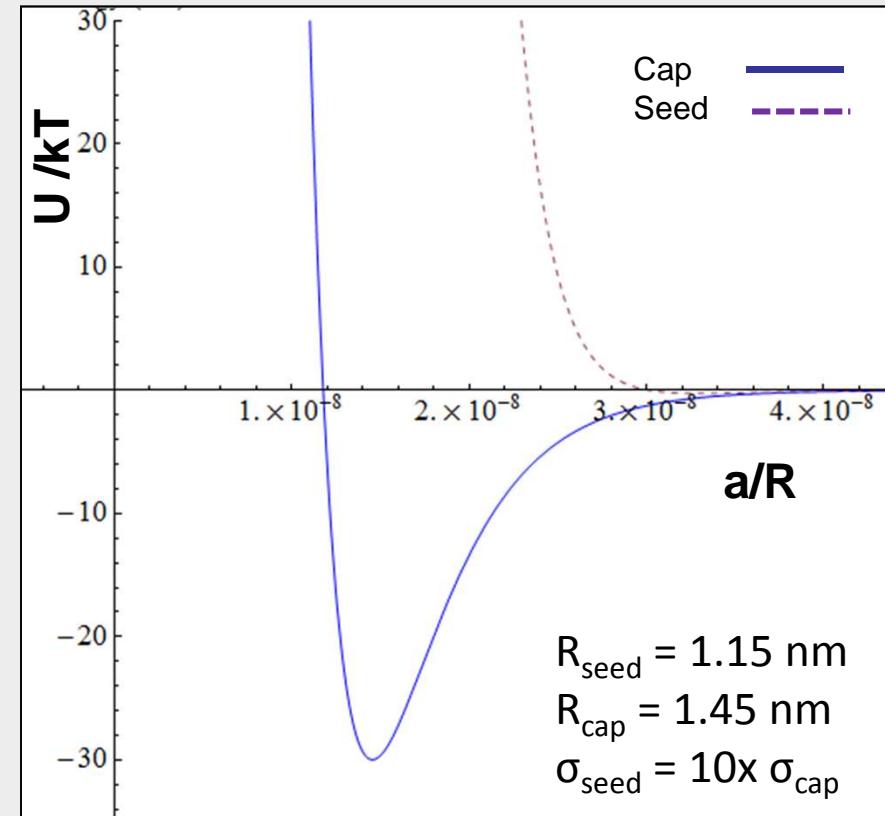


Creating differences:

- Different monomer (PS/PMMA)
- Charged/uncharged initiator

Current system:

- Charged protrusion
- PolyStyrene/PS particles
- Readily suspendable in water/3MP
- Promising ground-based measurement



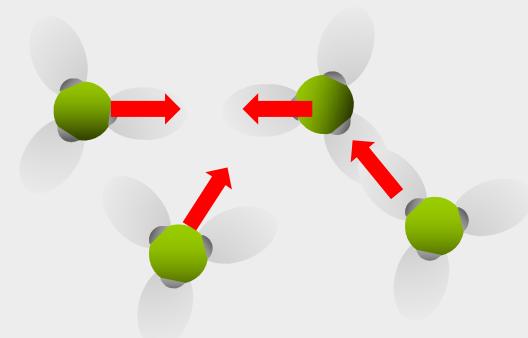
Simple calculation
Charge density difference only
Same temperature

Proposed Experiment

Temperature control

- Attraction on/off
- Follow structure formation
- “Reaction kinetics”

T ↗



Vary Temperature → Vary attraction strength

Vary Rate of change → Eqilibrium vs. out-of equilibrium

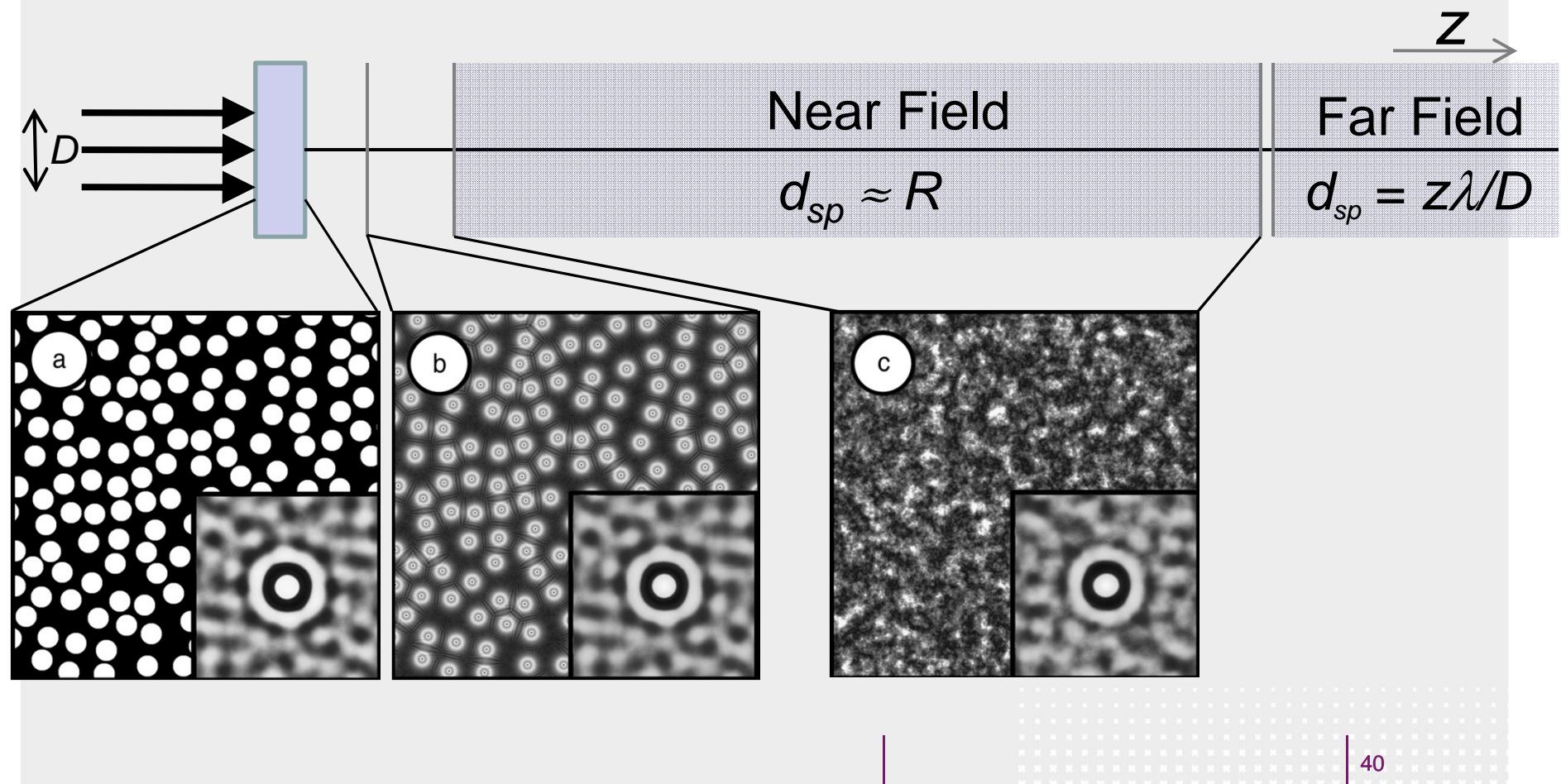
Reverse Temperature → Repeat Experiment

Image in real + reciprocal space



Proposed Experiment

Direct imaging + Near Field Scattering



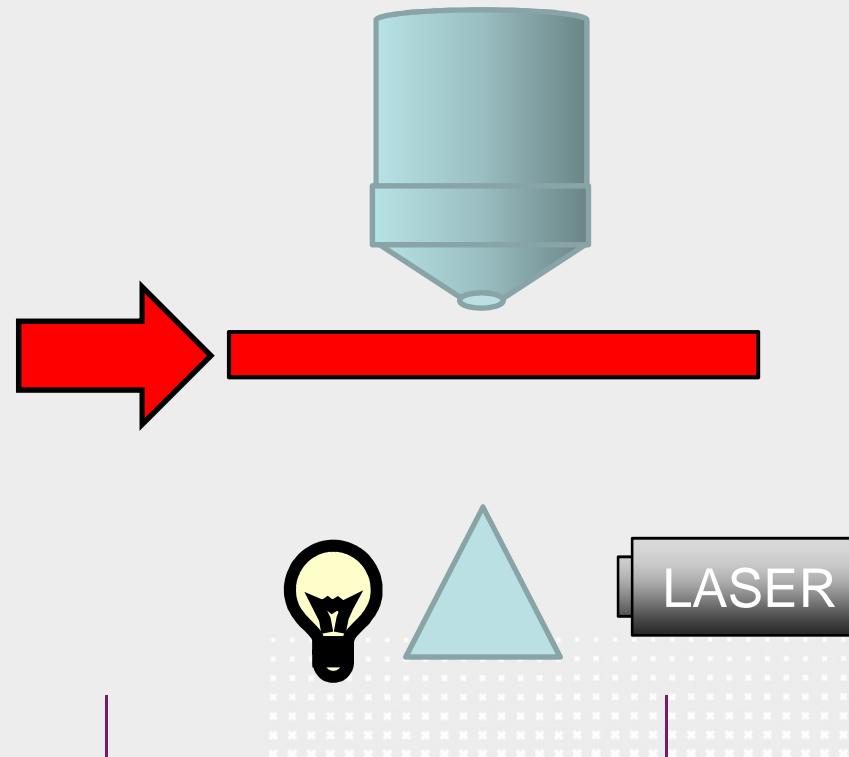


Proposed Experiment

1. Sample Cells

- Stirrer
- No bubbles in field of view
- Quartz cells
- Max 3 mm thick

ACE microscope

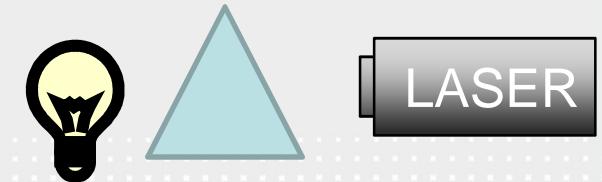
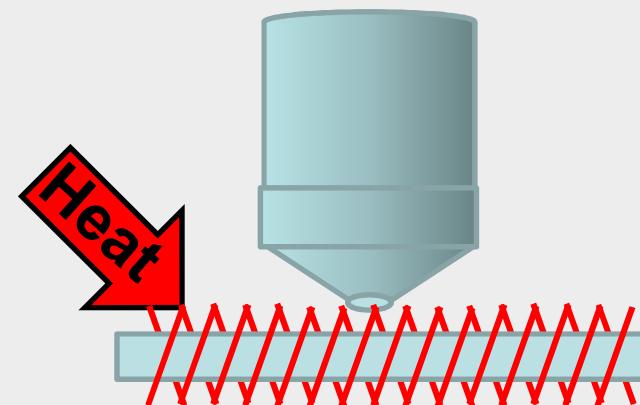


Proposed Experiment

2. Temperature control

- 0.5 °C steps, better 0.2°C
- Possible to heat samples individually

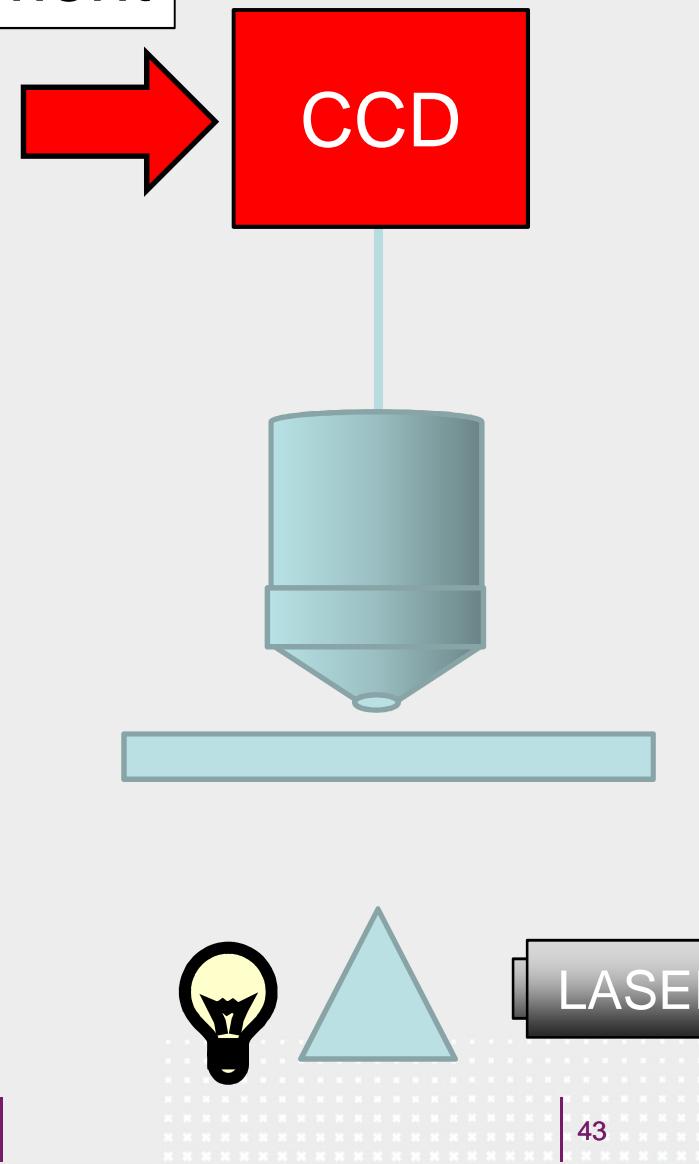
ACE microscope



Proposed Experiment

3. Camera

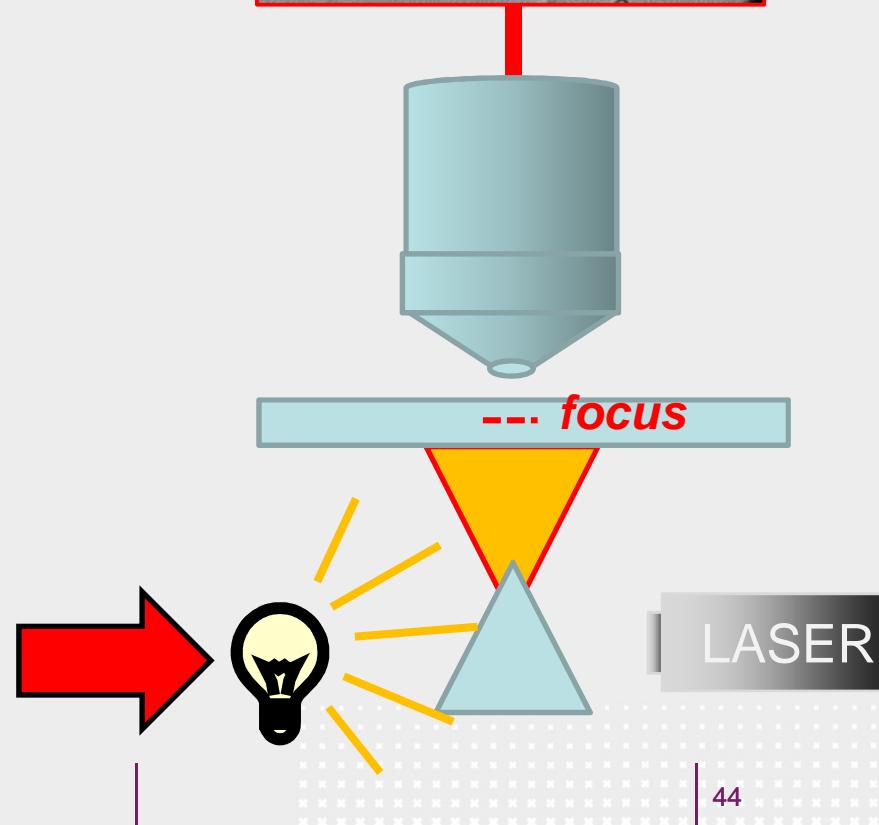
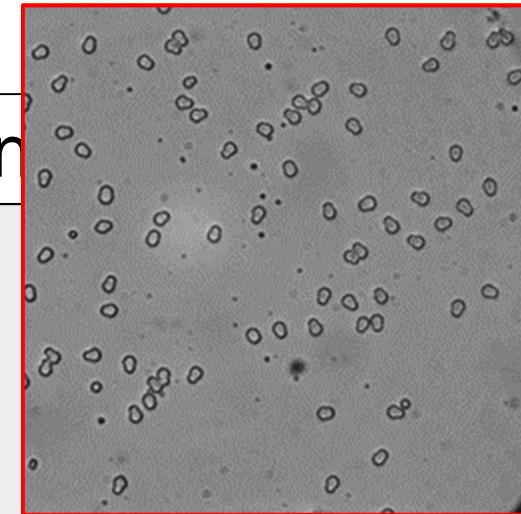
- 1024x1280 pixels
- Dynamic range: 12 bit
- Low signal to noise ratio



Proposed Experiment

4. Direct Imaging Mode

- White light illumination on
- Laser off
- Focus in sample

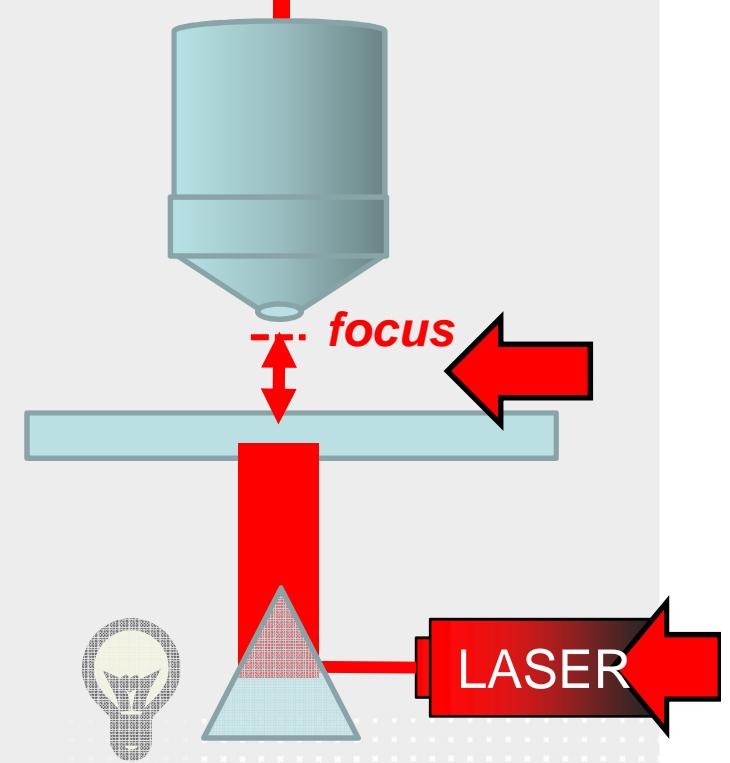
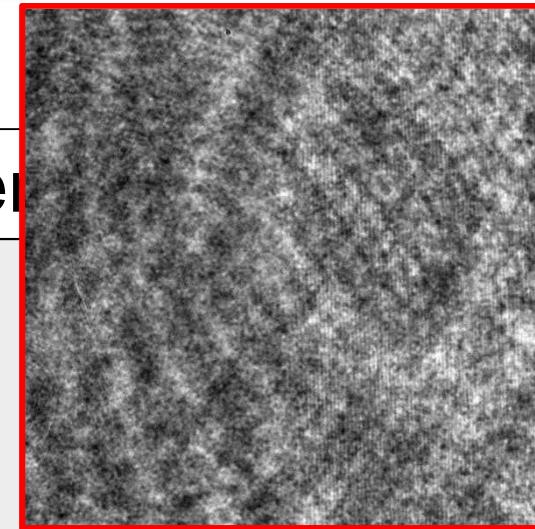




Proposed Experiment

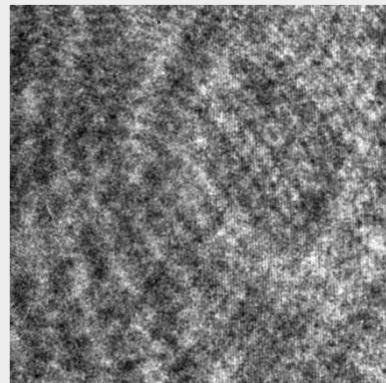
5. Near field scattering Mode

- White light off
- Laser on:
Beam Collimated
Coherence length ~ 3mm
- Focus above sample

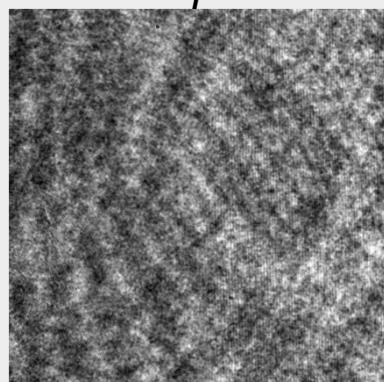


Proposed Experiment

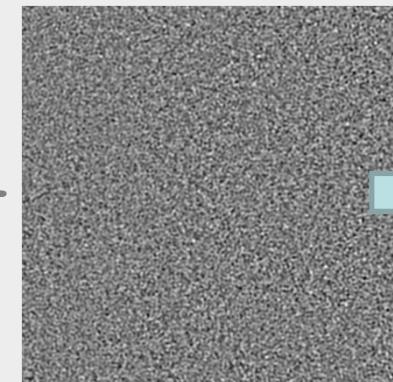
Raw image at t_i



Raw Image at
 $t = t_i + \Delta t$

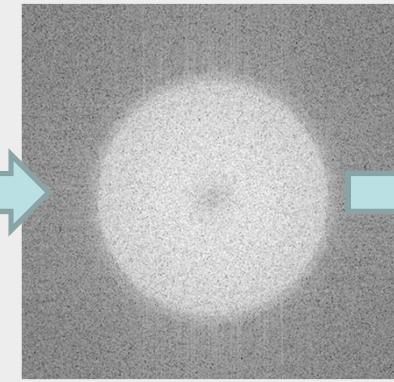


Subtracted
Image



$$D_i(x, y)$$

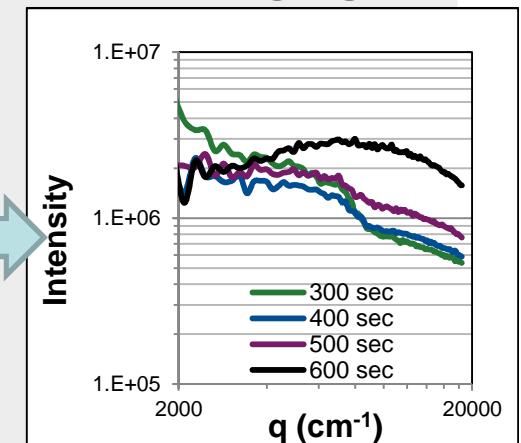
Power
Spectrum



$$S(q_x, q_y) =$$

$$\left| FFT[D_i(x, y)] \right|^2$$

Azimuthal
averaging



$$I(q)$$

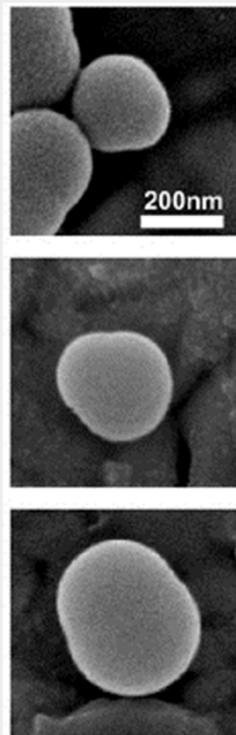


Proposed Experiment - Samples

1. Mono Patch



vary aspect ratio

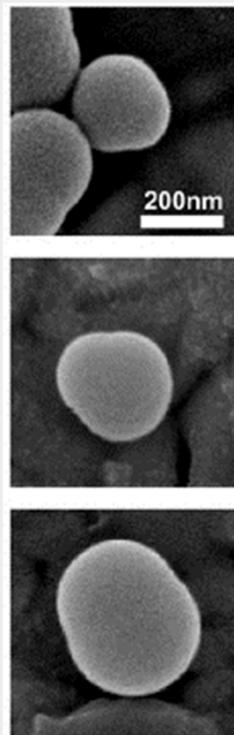


Proposed Experiment - Samples

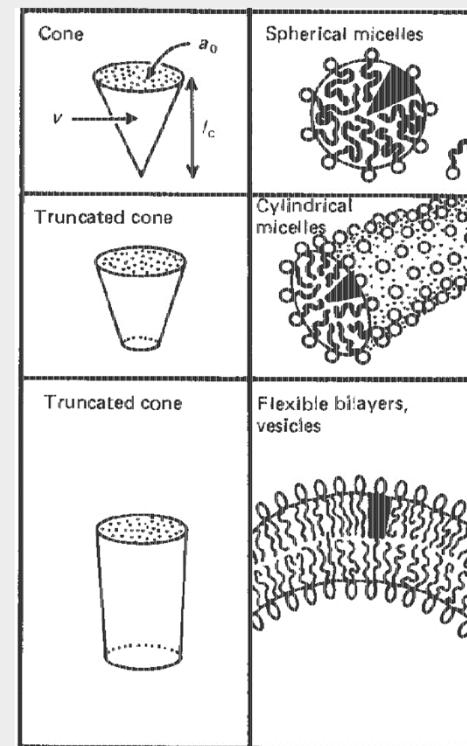
1. Mono Patch



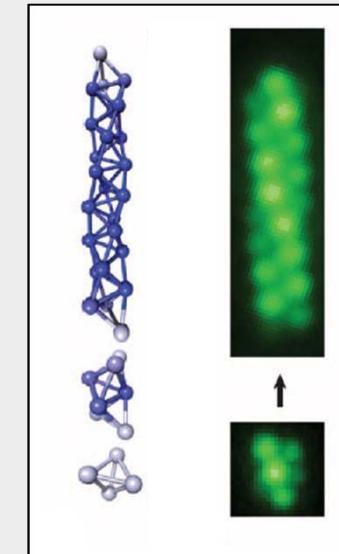
vary aspect ratio



Colloidal Micelles



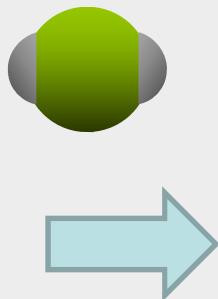
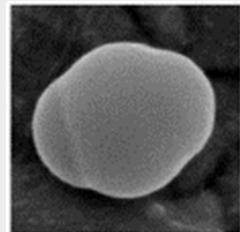
Helices





Proposed Experiment - Samples

2. Di-Patch

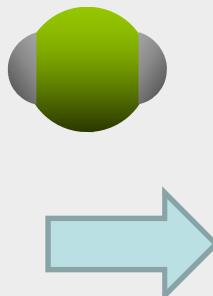
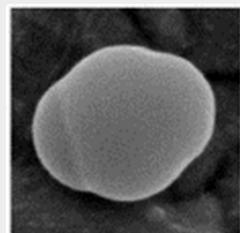


Colloidal Polymers



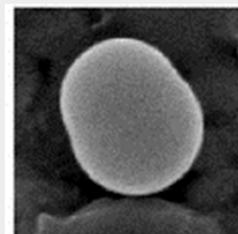
Proposed Experiment - Samples

2. Di-Patch

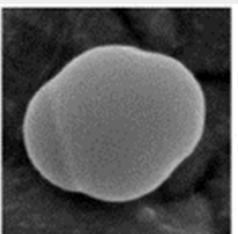


Colloidal Polymers

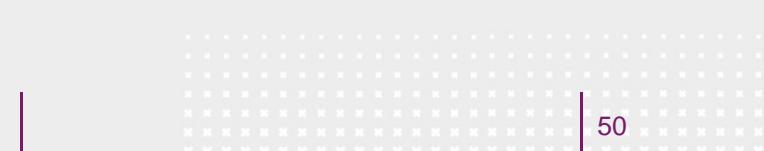
3. Mixtures
Mono Patch



+ Di-Patch

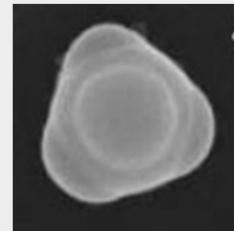


Molecules
Superstructures



Proposed Experiment - Samples

4. Tetra-Patch

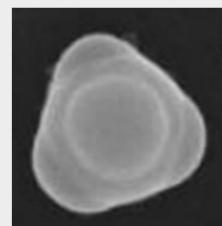
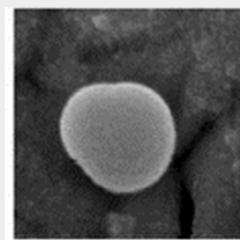


Diamond structure

3. Mixtures
Tetra Patch



+ Di-Patch



CH_4 , organic molecules

Succes Criteria

■ What do we want to see?

- Temperature - controlled assembly + Imaging
- Novel structures from anisotropic potential
- Control structure with attraction strength
- Follow Dynamics of 'molecular reactions'

Summary

- Growth of colloidal superstructures
- Direct T control of anisotropic potential
→ New equilibrium + out-of-equilibrium structures
- Real+reciprocal space imaging
- Colloidal Micelles, Helices, Polymer chains,
Diamond structure, complex molecules

Collaborators

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- Peter Bolhuis (Simulations, Amsterdam)
- T. Narayanan (ESRF Grenoble)
- D. Nguyen, D. Triet, J. Moons (PhD, Amsterdam)